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August 1979
Foam Applications in Theater of Operations Construction

FOAM OVERHEAD COVER SUPPORT (FOCOS) SYSTEM FOR DISMOUNTED AND MOUNTED TOW POSITIONS

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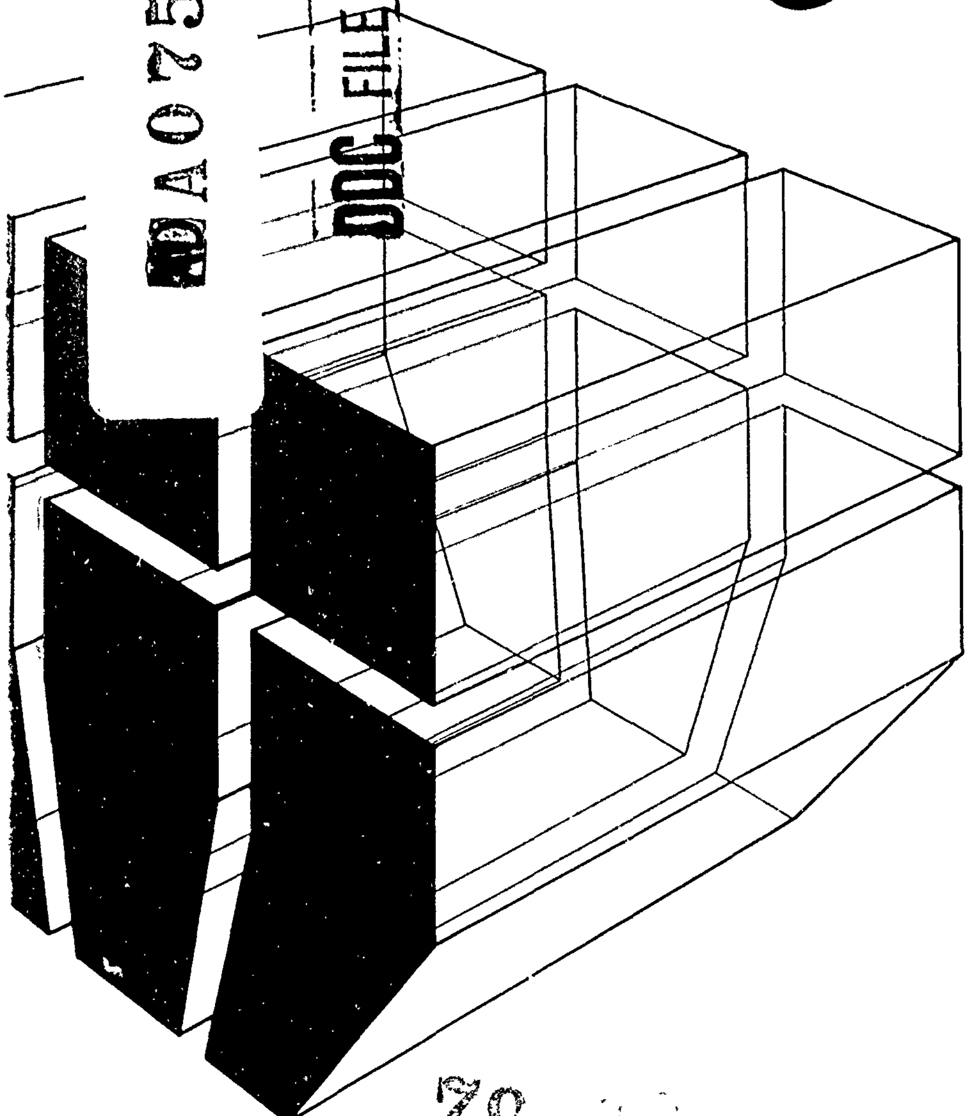

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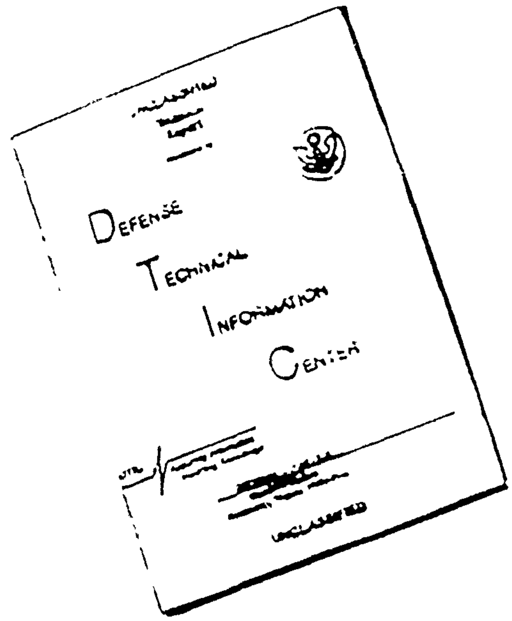

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This report presents the results of a concept development study of the use of polyurethane foam in constructing protective overhead cover support for TOW fighting positions.

Two principal methods of cover support fabrication were considered:

1. A two-component spray polyurethane fabrication foam applied on a prepared form.

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2. Hand-mixed polyurethane foam expanded within a fabric form.

In both cases, an arch-shaped support with a 4-ft (1.2-m) radius and a 5-ft (1.5-m) length was made. The foam-filled fabric form was selected as having the highest potential for successful application by weapon crews. Subsequent field tests of the selected system demonstrated that a TOW weapon crew can erect an effective cover support system in the field without special tools or equipment.

FOREWORD

This investigation was conducted for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), at the request of the U.S. Army Engineer School (USAES), under RDT&E Program 6.27.31A, Project 4A762619AT41, "Research for Base Development in the Theater of Operations"; Task 08, "Base Development, Design and Construction"; Work Unit 002, "Foam Applications in Theater of Operations Construction." The U.S. Army Mobility Equipment Research & Development Command (MERADCOM) requested special additional tests and provided funds via Intra-Army Order A 9055. The OCE Technical Monitor is Mr. G. E. McWhite. The USAES point of contact is 1LT Richard Ross of the Directorate of Combat Developments. The MERADCOM monitor is Mr. Harry Smith.

The work was performed by the Engineering and Materials (EM) Division, U.S. Army Construction Engineering Research Laboratory (CERL). Dr. G. R. Williamson is Chief of EM. Laboratory and developmental work were done at CERL, and the field demonstration and testing were done at Jefferson Proving Grounds, IN.

Appreciation is expressed to Dr. Robert Dinnat and CPT W. J. Cunningham for their suggestions and encouragement, to Mr. Robert Neathammer for the degree of protection study, to the personnel of Jefferson Proving Grounds for their splendid cooperation in the field testing, and finally to Bob Muncy, Bart Culbertson, and Steve Abate, all of whom put forth exemplary effort, often under very adverse working conditions, which contributed substantially to the study.

COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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FOAM OVERHEAD COVER SUPPORT (FOCOS) SYSTEM FOR DISMOUNTED AND MOUNTED TOW POSITIONS

1 INTRODUCTION

Background

The TOW* is the infantry's primary long-range anti-armor weapon and is therefore likely to draw heavy suppressive fire during battle. The TOW weapon position, however, presents a particular problem in overhead cover support. To be effective, the TOW gunner must maintain a line-of-sight visual contact with the target during the flight of the missile—usually 10 to 15 seconds. The development of an effective overhead cover support system for TOW fighting positions is necessary to prevent TOW weapons and crews from being destroyed before they can engage enemy armor.

Two recent studies were commissioned within the Department of the Army (DA) to investigate (1) the relationship between TOW survivability and overhead cover, and (2) methods for providing overhead TOW cover support.

A February 1977 study by the 2nd Brigade, 7th Infantry Division at Fort Hunter Liggett focused on the use of the TOW in strongpoint defensive positions designed to resist armor attack. The TOW positions in this study were constructed of large, heavy, conventional materials (e.g., sawn timber, plywood) which were difficult to haul forward from storage sites. The Hunter Liggett study concluded that there was an urgent need for:

1. Dismounted TOW crews to be able to independently construct protective cover.

2. Jeep-mounted TOW crews to construct cover with a minimum of engineer support.

The Waterways Experiment Station (WES), during another concept study, investigated methods of providing field-constructed overhead cover for TOW positions and developed a system using metal tube frames and canvas support to field-construct TOW covers.[1]

The Directorate of Combat Developments, U.S. Army Engineer School (USAES), requested the U.S. Army Construction Engineering Research Laboratory (CERL) to provide a low-weight, low-volume overhead TOW cover system. CERL then began an investigation into the use of low-density polyurethane foams for fabrication of foam overhead cover support (FOCOS) systems for TOW fighting positions.

Objective

The objective of this study was to develop a foam overhead cover support system (FOCOS) kit using foam plastic as a construction material for the simple and fast construction of low-weight, low-volume structures to support soil cover for the TOW weapon fighting positions.

Approach

This study was conducted in the following steps:

1. Geometric shapes and sizes acceptable for use as overhead cover for the TOW position were identified.

2. With the assistance of WES, the amount of soil cover required for protection from fragments of near-miss artillery projectiles was determined.

3. Probability studies were performed to indicate the degree of protection improvement offered by the proposed cover system.

4. Techniques of field forming selected support structures were developed.

5. Weapons effects tests were conducted to evaluate the adequacy of the design, fabrication techniques and materials, and the adequacy of the system in simulated near-miss artillery fire.

6. Tests were conducted to evaluate the size, weight, and simplicity of fabrication and cover construction of the proposed FOCOS kit.

7. The kit, construction, and weapons effects resistance were demonstrated.

*Tube-launched, optically tracked, wire command-linked guided missile

[1]Reynolds, LTC W. M., et al., *Customer Test Evaluation of Protective Structures for Mounted and Dismounted TOW* (USAIB, August 1977).

8. Long-term load-carrying capability of the FOCOS structure was determined.

9. The effect of temperature on foaming was assessed.

Scope

This study was limited to the development of a FOCOS kit for the TOW dismounted and jeep-mounted fighting positions. However, the materials and techniques developed may be adapted to cover support systems for other sizes of fighting positions.

Safety

The materials suggested for use in the FOCOS system do not adversely affect personnel if they are used in a well-ventilated area such as an open field. Although the polyurethane components used in the FOCOS system will burn if a flame is held against them, the canvas fabric skin used with the system is flame retardant; there is, therefore, no danger of ignition from weapon backblast or incidental fire sources such as cigarettes.

Mode of Technology Transfer

Technology transfer of the FOCOS will be accomplished by direct transfer to MERADCOM with continued assistance regarding training of the TOW crews, the issuance of a Training Circular, and draft changes to FM 5-15, *Field Fortifications.*

2 DEVELOPMENT OF THE FOCOS SYSTEM

Preliminary Tests

Since information on the use of polyurethane foams applied with substantial soil loads was not available, CERL planned and conducted a series of preliminary tests to assess the potential soil-loading capability of foam. These tests were designed to evaluate the foam's ability to support soil cover and to withstand shock-loading from explosive detonation resistance while soil cover was in place.*

Two geometric shapes, domes and arches, were initially tested, since the size of the TOW weapon (Figure 1) requires an area approximately 8 ft (2.4 m) in diameter to allow room for the weapon and crew.

Reinforcing materials were also evaluated during the preliminary tests. Aluminum insect screen wire, nylon mesh, and heavy reinforcing wire mesh were used with the foam in various structures to determine if these materials would improve the strength or load resistance of the foam. Table 1 describes the reinforcing materials used during these tests.

The dome and arch specimens were prepared in the laboratory by spraying a typical low-density polyurethane foam onto prepared forms. Commercial spray equipment was used to mix and spray the foam material; reinforcing materials were encapsulated in the sprayed foam. Specimens were removed from the molds immediately upon cure, usually less than 10 minutes after the spraying operation ended. Table 2 describes the foam material used in the preliminary tests.

The dome and arch test structures (Figures 2 and 3) were transported to Jefferson Proving Grounds, IN, and tested with varying amounts of soil cover and TNT charges detonated at predetermined distances from the structures. Table 3 gives the test conditions and results.

Laboratory Development

Foam Reinforcing Materials

Laboratory studies were conducted on spray-applied foams encapsulated with reinforcing materials (see Table 4). Simple beam specimens with the reinforcement near the tensile face were tested in flexure. Some improvement in strength and stiffness was noted for every reinforcing material considered; however, when the bulk, weight, field use, and cost of the reinforcing materials were taken into account, a lightweight coated nylon fabric was selected as the most promising reinforcing material. Table 5 presents the selection criteria.

Arch Configuration

The geometric shape selected was the arch, since this shape offers the largest area of protective cover while allowing the greatest open area both front and rear. The arch is also the easiest shape to cover with

*WES provided CERL with information regarding minimum soil-cover depth. It was established that a minimum soil-cover thickness of 18 in. (0.46 m) was required to resist fragments from 155 mm and smaller shells detonating 10 ft (3 m) and further from the overhead cover structure.

soil and allows the best distribution of soil load. Furthermore, the mound created by the covered arch is a natural shape that, when camouflaged, blends more easily into the background than do more angular shapes.

The arch dimensions developed by this study are 8 ft (2.4 m) in diameter and 5 ft (1.5 m) long (Figure 4). The pivot point of the TOW launcher is positioned in the arch such that the forward end of the launch tube projects out from under the cover (Figure 5). The rear of the launcher projects slightly out the rear of the shelter, so that backblast reflection into the shelter is minimized. The locking handle, located on top of the weapon (Figure 6), is placed near the highest area of the shelter to allow clearance for its upward operation during loading of the weapon. When the weapon is placed within the shelter in this manner, it is allowed maximum traverse and elevation depression, with respect to the front and rear opening of the arch.

Lightweight tubular frames were evaluated as a means to regulate arch shape and size. The tubular frame components consisted of two semicircular bows 8 ft (2.4 m) in diameter and eight straight sections 5 ft (1.5 m) long (Figure 7). Each component was segmented to allow slip-together assembly from a folded-down configuration 18 in. (0.5 m) long (Figure 8). The parts of each component were held by a nylon cord which extended through the tube sections and was tied at each end of the component. A plastic pipe frame and two metal pipe frames were tested. The plastic pipe frame was made of ½ in. (13 mm) PVC pipe. One of the metal frames was made of ½ in. (13 mm) steel tube and the other was made of ¾ in. (18 mm) aluminum tube. The plastic pipe tube frame weighed approximately 17 lb (3.6 kg) and each of the metal frames weighed approximately 15 lb (7.2 kg).

The tube frames were easily and rapidly assembled and the slip-joints were held fast by tightening the internal cord and lashing one end to keep it taut. A sheet of lightweight nylon fabric was stretched over the arch frame (Figure 9) and secured on the ends by sandbags or stakes driven at the base of the frame. Approximately 4 in. (100 mm) of foam material was then sprayed onto the nylon fabric. The tube frame could then be either left in place after the foam had set, or removed for use in forming another arch.

Arches formed by this method were not uniformly curved, but consisted of a series of segments with joint lines, caused by the bow-to-bow crosspieces of the frame. This shape weakened the arches by causing stress concentrations at the joint lines, and support of soil weight was very marginal. No tests were conducted to determine the ability of these arches to sustain dead loads over a period of time.

Foam-Application Alternatives

Vehicle-Housed Equipment

The initial arches, formed in the laboratory, were sprayed using equipment that is appropriate for the field only when used by a trained operator. This equipment requires a compressed air supply and 220 V electrical power supply and thus should be mounted in a vehicle specifically designed for foam spraying.

If the vehicle design includes a heating unit, this equipment can be reliably used under a variety of field conditions. (This capability was demonstrated by spraying foam onto a snow arch form that had a nylon cloth cover as a reinforcing layer for the foam. Outside temperature was -10°F [-24°C] during the spraying and there was a light wind; the foam spray equipment was kept in a heated building. The resultant arch was considered adequate for FOCOS use.)

Pressurized Kits

Prepressurized dual cylinder foam spray systems are commercially available in nonreusable kit form. Two kit sizes were evaluated for potential use in FOCOS fabrication: a 30 lb (13.7 kg) kit and an 80 lb (37 kg) kit. Tests determined that three 30 lb (13.7 kg) kits were necessary to produce enough foam cover for a single arch. Although one 80 lb (37 kg) kit was enough to complete a single arch, the amount of foam it produced was considered only marginally adequate. In addition, neither the size and weight of the pressurized kits nor the sensitivity of their spray application under the wide variety of environmental and temperature conditions found in the field were considered satisfactory for FOCOS fabrication.

Handmixing—Direct Application

The most reliable method of producing foam in the field is by handmixing the two-component foam system, pouring the foam mixture into place, and allowing the foaming to take place directly on the

structure surface. This method does not work with arch shapes, however, because of runoff that takes place before foaming occurs. Regulation and control of foam thickness and uniformity is also impossible for an arch shape using this method.

Handmixing—Fabric Bag

The idea of using a fabric bag to contain handmixed foam was conceived and evaluated as a means to provide efficient, reliable FOCOS fabrication. The first cloth bags were designed and made using 2 oz/sq yd coated nylon fabric. The bag length was 12.5 ft (3.8 m) to correspond to the perimeter of the arch. The width of the bag was 5 ft (1.5 m)—the width of the fabric that was immediately available.

The original design of the bag was such that its inside and outside face lengths were different, to account for the length difference that would be caused by the arch thickness. Four-inch (100-mm) curved side panels were sewn to the edges of the faces along with interface ties of nylon cord to regulate the separation of the faces and thus limit arch thickness. These ties were evenly spaced about 8 in. (200 mm) apart over the whole arch. It was originally thought that such a bag design would automatically form an arch when foam was expanded inside it. However, when the self-shaping, low-porosity arch bag was inflated with low-pressure air, it showed little tendency to form itself into an arch. Similar results were obtained when the bag was filled with foam. Thus it was concluded that the additional complexity of sewing an arch-shaped bag was unnecessary, and the design was replaced by a simple, straight-edged, panelled bag.

Foam Selection—Fabric Bag

The foam selected for use with the foam-in-bag concept had the same density as the sprayed material used in the preliminary tests. However, the foam reaction rate had to be considerably slower than the 10 to 15 seconds typical of spray-applied foam to allow time for the foam to be handmixed and poured into the bag. Time also had to be allowed for distribution of the foam in the bag; therefore, a slow-rising foam was used. Table 6 describes the foam selected for the foam-in-bag concept.

Distribution problems were encountered during the initial attempts to fill a fabric bag with foam. The quantity of foam needed to fill the bag was estimated to be 60 lb (25 kg) or 30 cu ft (0.8 m^3) of 2 lb/cu ft (32 kg/m^3) density. However, unconstrained density of foam was not achieved. The bag's large area-to-volume ratio and the restraint offered by the bag to the foam flow caused an overall density of about 2.8 lb/cu ft (44.9 kg/m^3). As a result, the bag did not fill completely. The amount of foam mixture introduced was adjusted to compensate for the density increase, but continued inadequate foam distribution prevented the bag from filling completely.

Foam-in-Bag Arch Construction

During the first attempts to make a foam/bag arch, two equal batches of foam materials were mixed and poured into the bag through openings in the ends of the bag, near the center of the bag's width (Figure 10). After introduction of the foam mixture, and before foaming, each end of the bag was raised to encourage the material to flow toward the center. This method did not work well. The foam-introduction points were then repositioned to the bag edges, midway at the length of the bag (Figure 11). This method improved foam distribution; however, the bag still filled unreliably. In addition, the interfacial ties seemed to offer too much flow resistance to the foam, particularly when it was gelling near the end of the expansion phase. It was concluded, however, that the foam-in-bag concept offered the best alternatives for FOCOS.

Forming an already filled foam/fabric bag into an arch was then considered, since the foam cure stage includes a short period of time (2 to 3 minutes) when the foam is rubbery and plastic. It is possible to shape the bag into an arch during this phase. Three approaches were evaluated:

1. The ends of a foam-filled bag were lifted toward each other until they were about 8 ft (2.4 m) apart, and held until the additional curing of the foam made the shape stable (4 to 5 minutes) (Figure 12).

2. A foam-filled bag was placed on one of its long edges and two persons bent the bag's edges toward each other while a third person attempted to make the arch as uniform as possible (Figure 13).

3. A tube frame (Figure 14) was set up and a foam-filled bag was placed over it while the foam was rubbery.

It was determined that none of these methods provided good, uniform, arch shapes. The first two

methods produced only a slight arch and the third proved the tube frame too flimsy for field use as an arch form.

The importance of arch uniformity was emphasized during soil cover application tests. It was observed that if a nonuniform arch was used, stress concentrations in excess of the material's strength and stiffness capacity would develop in the more highly stressed zone, and the structure would gradually collapse (Figure 15).

It had been assumed early in the study that only a small design safety factor would be used in order to minimize the weight and volume of materials required for the cover support. The failures caused by nonuniform arch shape emphasized the lack of over design in the arch.

The results of a degree of protection probability study are summarized in the Appendix.

Field Tests

A field test was conducted at Jefferson Proving Grounds, IN, to evaluate the various techniques developed for FOCOS, and to identify the technique with the best potential for use in completing FOCOS concept development.

Test specimens included an arch sprayed in the laboratory with spray equipment, an arch field-sprayed with foam from prepressurized spray kits, and two foam/fabric bag arches. The tests were designed to compare the performance of laboratory-prepared specimens to field-prepared specimens, to evaluate soil-cover application methods, and to determine the resistance of foam/fabric arches to soil-cover dead loads and combined soil dead loads and shock loads from detonated TNT and artillery projectiles.

To determine loads introduced by the detonation shock front, shock overpressure measurements were recorded in some of the tests. Sensors were placed at the foam/soil interface nearest the explosion. Test results indicated that the soil (both clay and sand) apparently attenuated the shock wave. Figure 16 shows typical acceleration curves. Table 7 shows the relationship between charge distance and overpressure. The anticipated pressure, based on charge weight and distance curves developed by Ballistics Research Laboratory (BRL), were not reached at the foam/soil interface. The combination of soil attenuation, structure response, and, perhaps, accelerometer sensitivity may have contributed to these low shock loads.

The test series provided several conclusions:

1. The foam/fabric arch was the best of the test specimens

2. The arch bag can be filled and formed successfully in the field

3. To provide maximum soil and shock load resistance, the arch shape must be uniform

4. Soil cover must be placed so that load distribution is reasonably equal

5. If an arch can withstand the dead load from soil cover, it can also withstand both the dead load and the transient shock overpressure live load from 155-mm artillery round (or equivalent) detonations 10 ft (3.3 m) or further away

6. The FOCOS system cannot withstand direct hits or very near misses by 81-mm mortar (or equivalent) and larger detonations.

Test results are summarized in Table 8.

Foam/Fabric Arch Refinement

The foam/fabric arch materials and the filling and forming method had to be refined since the lightweight coated nylon used in the foam/fabric bags had not performed as well as desired in the field tests. And, although a neoprene-coated nylon fabric had tested very well, it was believed that the load resistance of the bag arch could be enhanced by using stronger fabric and by an improved filling/forming technique.

The fabric bag was redesigned to simplify its fabrication process. Edge panels and interfacial ties were eliminated and the top and bottom faces were sewn directly to each other along the edges all the way around the bag. Ties were replaced by sewing the two faces together at intervals of approximately 10 in. (0.25 m). This wider spacing allowed greater face-to-face thickness in the arch; the volume change was compensated for by having the faces flush at the sewn spots. However, as the fabric faces moved apart during foam expansion, there was a corresponding reduction in the bag's length and

width; the bag dimensions were changed to allow for this reduction. Heavier fabrics of treated and untreated cotton canvas were selected to replace the lighter-weight nylons used in the original bags. Zippered openings were used to ease closure of the openings after the foam mixture had been poured into the bag. (Previously, the openings had been held closed by hand during the foaming process.) Tests indicated that the zippers worked well and that the number and locations of the openings on the foam/fabric bag were satisfactory. Figure 17 shows the new bag design. Field tests also showed that a folded piece of cardboard served both to hold the zippered openings apart and to form a trough to direct the foam liquid into the bag. It was also noted that while the new bag design changed the width of the bag approximately 15 percent during foam expansion, the change in length was negligible.

Foam distribution was improved by dividing the foam into two batches and pouring half of each batch into an opening at each end of the bag. The openings were placed approximately one-third the distance from the edge of the bag to its center to provide the shortest possible flow distance for the foaming material. The heavier fabric also helped the flow by forcing the foam toward empty areas in the bag. Tests showed that this method of bag filling provided excellent foam distribution.

Arch Shape vs Dead Load Capacity

As noted above, field tests indicated a need to evaluate the relationships between arch shape and dead load capacity. Therefore, an additional test was devised in which a canvas fabric bag was filled with foam, shaped to a very uniform arch over a plywood mold, and loaded to simulate a weapon position.

First, a trench was dug about 1 ft (0.3 m) deep and slightly longer and wider than the base of the arch. The arch was placed in the trench and 2-½ ft (0.76 m) of loose soil was piled against its ends. A measuring device was placed under the arch so that centerline and midheight deflections could be roughly monitored during loading (Figure 18). To allow easy calculation of loading weight, sandbags weighing approximately 40 lb (18 kg) each were used as the dead load. Sandbags were placed on the arch on each side on top of the soil that was against the arch's ends, resulting in a slight inward movement at the arch's midheight points. Weight was then placed across the center of the arch (Figure 19) to counter the midheight movement. Sandbags were thus loaded on the arch until an 18-in. (0.48-m) thick cover was attained (Figure 20). The total weight was calculated at approximately 180 lb/sq ft (879 kg/m^2), which exceeded the approximate weight of a loose soil layer of 18 in. (0.48 m). [Loading the arch by hand-shovelling soil would cause less drastic localized loading than the sandbagging method used during this test. However, it would still be important to first restrain the arch's ends well, build up each of the arch's sides to approximately 3 ft (.9 m) of the arch height, and then load the arch across the top.]

The response of the arch was measured daily for 2 weeks; Figure 21 depicts the change over this 2-week period. The arch apparently compressed somewhat, as indicated by a decline in height with an absence of outward thrust of the midheight points. The test was terminated after 2 weeks since the probable use of the FOCOS system is less than 1 week.

Long-Term Loading

At the request of MERADCOM, a test was conducted to measure creep under 12 in. (.3 m) of earth cover over a period of at least 30 days. Weather/temperature conditions were recorded during this time.

A foam arch similar to the one tested previously was set up on a concrete pad base and loaded with sandbags to simulate earth cover exceeding 12 in. (0.3 m) in depth. Actual depth was about 16 in. (0.38 m) of sandbags. A polyethylene film cover was placed over the sandbag load to limit the incursion of water during rain or snowfall. A measuring device was centered inside the arch so that deformations at the centerline and at points 45 degrees from horizontal could be measured.

Deformation response to the load began immediately and the rate of deformation gradually declined as time passed. At the end of the second week, a hard freeze occurred and measurable deformation practically stopped. The halt in deformation was attributed to two factors: increased foam stiffness at the lower temperature and probable consolidation of the load by freezing of the small amount of moisture in the sand, resulting in bridging action. Table 9 shows the movement of the reference points and the temperature (daily high and low) from 20 December 1978 to 20 February 1979. After the first 30 days, only periodic readings were taken in the

long-term test. Table 10 shows the recorded movement of a similar test of two weeks' duration conducted during August 1978. Note that in both tests the center showed deformation (downward) while the left and right 45-degree points did not move outward. This indicates that the foam was compressing or acting as an arch in bending above the 45-degree points where it was constrained against outward movement by the sandbag load.

Arch Formation

A uniform arch can be simply and reliably formed in the field using (1) a cord that is premeasured to the length of the required arch radius and (2) six stakes. First, one end of the cord is pinned to the ground by a nail; the remaining end provides the necessary radius. This end is used to evenly space the six stakes until they form a semicircle. Note that 6 in. (0.15 m) of each stake should project vertically out of the ground (Figure 22). The fabric bag is then foam filled adjacent to the stake arc. During the foam's rubbery phase, the bag is stood on edge by two persons and shaped around the series of stakes. The bag is supported vertically during the additional 4 to 5 minutes required for the foam to harden to a self-supporting rigidity. Three cords can be used to tie the ends (base) together to assist in shaping the arch (Figure 23).

FOCOS Kit Development

The materials identified by this study as the best for the overhead support system were assembled into a compact kit form. The kit container is a weatherproof, solid fiberboard box (V3S) designed to fully telescope. Its dimensions are 18 in. long, 12 in. wide, and 18 in. high (0.56 × 0.3 × 0.56 m). (Figure 24). The bottom half of the box contains four 2-gal (8-ℓ) oblong steel cans with screw-top closures (Figure 25). Two of the cans contain one component of foam material A, and the other two cans contain foam material B. Corrugated paper board separators are placed between the cans to prevent damage during shipping or handling. The folded fabric form is placed on top of the cans. The radius cord, two mixing paddles, and six 1 × 2 × 12 in. (25 × 50 × 305 mm) sharpened stakes are placed on top of the fabric form (Figure 26). The top half of the box is then placed over the bottom half (Figure 27), and the box closed by taping or strapping. Table 11 provides approximate weight and cost data on the kit components.

The kit provides a low-volume, low-weight, low-cost method of providing protective overhead cover support for the dismounted TOW weapon crew. Two kits can be used to form two arches which, when placed end to end over a prepared trench and covered with soil, can provide overhead cover for the jeep-mounted TOW crew.

The size, weight, cost, and logistical burden of the FOCOS kit compare very favorably with the kits developed during the WES study and the materials used in the Fort Hunter Liggett study. Table 12 compares the WES kits and the FOCOS kit. (The exact amount of material used in the Fort Hunter Liggett study could not be determined, but was apparently large based on the study's overall comments regarding the strongpoint defensive position.)

3 DEMONSTRATION AND TEST

Field Demonstration

A field demonstration and test was conducted at Jefferson Proving Grounds (JPG), IN. Representatives from OCE, USAES, WES, MERADCOM, JPG, and CERL attended as observers.

The kit components were displayed, and the foam/fabric arch forming and covering procedures were demonstrated by two people working simultaneously through the following steps:

1. Open kit container and remove contents.

2. Place the six stakes in a semicircle using radius cord for spacing (Figure 28).

3. Lay out fabric form zipper side up; open zippers; make a cardboard trough for each opening (Figure 29).

4. Place half of kit container and one mixing paddle on each side of fabric form, near one of the openings (Figure 30).

5. Place one can of foam material A and B components beside each box half (Figure 31).

6. Pour component B from can into box. (Note: an air vent pierced opposite the can opening speeds pouring) (Figure 32).

7. Pour component A from can into component B in box (both operators must do this simultaneously).

8. Mix A and B components vigorously for approximately 30 seconds—longer if the temperature is below 50°F (10°C) (Figure 33).

9. Pour approximately half the foam mixture into each of the openings in the sides of the bag (Figure 34).

10. Remove cardboard trough and close zippers.

11. Allow mixture to foam without disturbing for approximately 3 minutes; i.e., until the bag is filled. (Note: the sounds of some threads popping may be heard at the end of the foam's expansion phase.)

12. When the foam feels rubbery, stand the foam/fabric bag on edge and shape around the line of stakes. Tie spacing cords across base of arch.

13. Support the arch on end around the stakes until the foam hardens—approximately 4 to 5 minutes.

14. Dig in the weapon position to allow the base of the arch to be set down into the ground 1 to 2 ft (0.3 to 0.6 m). Fill excess dirt past the ends of the position on each side of the designated field of fire.

15. Place arch into excavated position before or after (preferably after) the TOW is in the position. Drive stakes against the ends of the arch (Figure 35).

16. Pile dirt against the ends of the arch until it is about 2-½ ft (0.76 m) high on each end (Figure 36).

17. Place a row of sandbags along each edge of the arch all the way around the arch from one side to the other. Note: the more sandbags used, the easier the loading will be (Figure 37).

18. Place sandbags or shovel dirt onto the arch until approximately 18 in. (0.46 m) depth is reached. IT IS VERY IMPORTANT TO LOAD THE ARCH EVENLY THROUGHOUT THE COVERING PROCEDURE (Figure 38).

Test

Tests were conducted on previously prepared positions while the observers were present. Problems were experienced with some of the positions that had been prepared 2 days before the test date since a heavy rainfall [about 3 in. (75 mm)] had changed some of the clay soil used as end fill into muck. As a result, the weight on top of the arches was not countered by lateral support and two of the test/display dismounted TOW positions collapsed during the night prior to the test. (Note: such failures can be prevented by using end restraints—such as stakes driven in the ground against the arch—to resist lateral movement.)

Bare TNT charges, 155-mm artillery projectiles, and 81-mm mortar rounds were detonated at various locations to the side of the remaining previously prepared test structures. Table 13 lists the test configurations and results.

The test results were essentially as expected, showing that misses of 10 ft (3 m) or more caused no significant damage to the structure, while very near misses and contact detonations caused failure (Figure 39).

4 TEMPERATURE EFFECTS ON FOAM

MERADCOM required the determination of foaming time, foam density, and performance under field-type conditions at temperatures of 0°F (-18°C) and 32°F (0°C) or minimum temperature at which the foaming and forming actions were satisfactory.

Two series of tests were performed. The first determined foaming time and foam density resulting from 1-lb (.45-kg) batches of two foam systems of material conditioned at 10°F (6°C) intervals from 70°F (21°C) to 0°F (-18°C). One was on the foam system demonstrated at JPG and the other was the same material but modified by addition of 3 percent of low temperature active catalyst. Table 14 gives the test results. The second series of tests consisted of determining the foam's performance under field-simulated conditions of low temperatures of 0°F (-18°C), 20°F (-7°C), and 32°F (0°C). The materials (foam chemicals, fabric forms, and mixing containers) were conditioned to the test temperature in an environmentally controlled chamber. The tests were performed outside when the temperature was at the same point as the conditioned materials. A separate test was conducted in which the materials were maintained at 60°F (16°C) and mixing, foaming, and forming were done at 0°F (-18°C). Table 15 gives the results of the tests. In view of the increased density of foam found in the first test series, the

volume of the fabric form was reduced about 40 percent by placing additional face-to-face attachment points at about the center of the 10 in. (254 mm) grid spacing used previously. An arch was made (at room temperature) and loaded with sandbags to assess the effect of reducing the section thickness of the arch. In 2 days under load the reduced-section arch performed satisfactorily with slightly more deformation than the thicker-section arch.

The foaming and forming are satisfactory at temperatures of about 30°F (-1°C) and above if all components are at that ambient temperature and the form volume is reduced as described above. Below that temperature, foaming becomes increasingly difficult until at about 0°F (-18°C) no foaming occurs. Foaming and forming arches at temperatures as low as 0°F (-18°C) is possible, however, if the materials are kept at around 50 to 60°F (10 to 16°C) until just before the activity.

5 POSSIBLE ALTERNATE USES OF THE FOCOS KIT

Decoy Positions

The FOCOS kit could be used to erect a decoy TOW position. With partial camouflaging, very little soil cover would be required to give a stable, visual decoy position. As an added deceptive measure, the position could be easily rigged with pyrotechnic devices, such as a field artillery simulator, that could be fired at or near the same time as the TOW. The simulated backblast may create uncertainty among the opposing force as to where to direct their fire, and would help protect the TOW position by reducing the likelihood of return fire engagement.

Buoyancy/Hasty Pontoon

Each FOCOS kit, when deployed as a flat form, could provide approximately 1200 lb (682 kg) of flotation capability. This capability might aid in transport of men and/or equipment across slow-moving streams or lakes. Two or more forms could be bound together to support larger pieces of equipment.

Shelters

The foam/fabric arch is watertight and could be used without soil cover for weather-protective shelters for personnel. If no soil load is to be applied, a larger covered area could be attained by leaving the foam/fabric bag flat until hardened and forming lean-tos by placing the bags against each other or against a cliff or bluff. In addition to providing waterproof protection, the foam is an excellent thermal insulator and might allow the maintenance of a better environment for the soldier.

6 CONCLUSIONS

1. A foam overhead cover support system is practical to construct in the field environment.

2. An arch-shaped foam/fabric cover support covered with 18 in. (.46 m) of soil can withstand near-miss artillery projectiles up to 155 mm.

3. The FOCOS kit is small and lightweight in providing cover support for the TOW position.

4. Field fabrication techniques and procedures are simple and require no special equipment.

5. The FOCOS system substantially increases protection of the TOW weapon and crew against indirect fire.

6. Thirty-day load-carrying capacity of the arch is adequate.

7. Foaming and forming are practical at 32°F (0°C), marginal at 20°F (−6°C), and unsuccessful at 0°F (-18°C). However, foaming and forming arches can be done at 0°F (-18°C) or higher if the foam materials are kept warm or are heated until just before the operations.

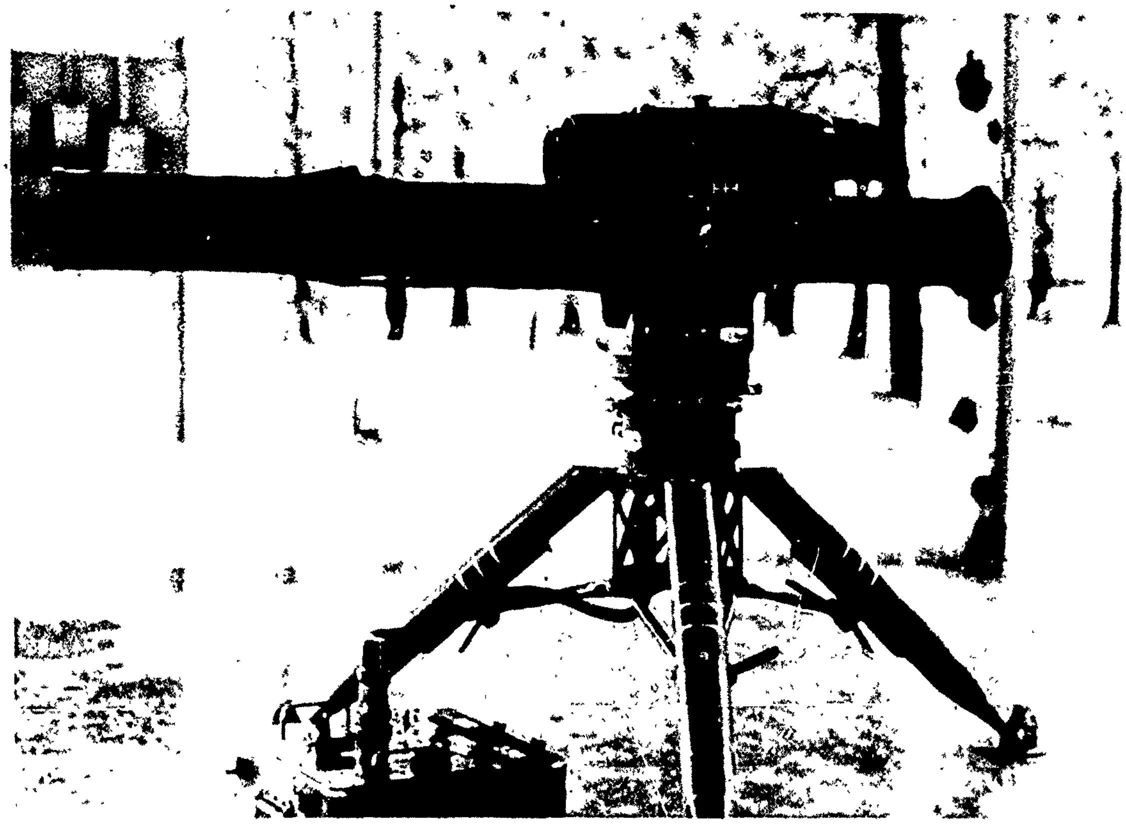


Figure 1. The TOW weapon.

Figure 2. Dome test structure.

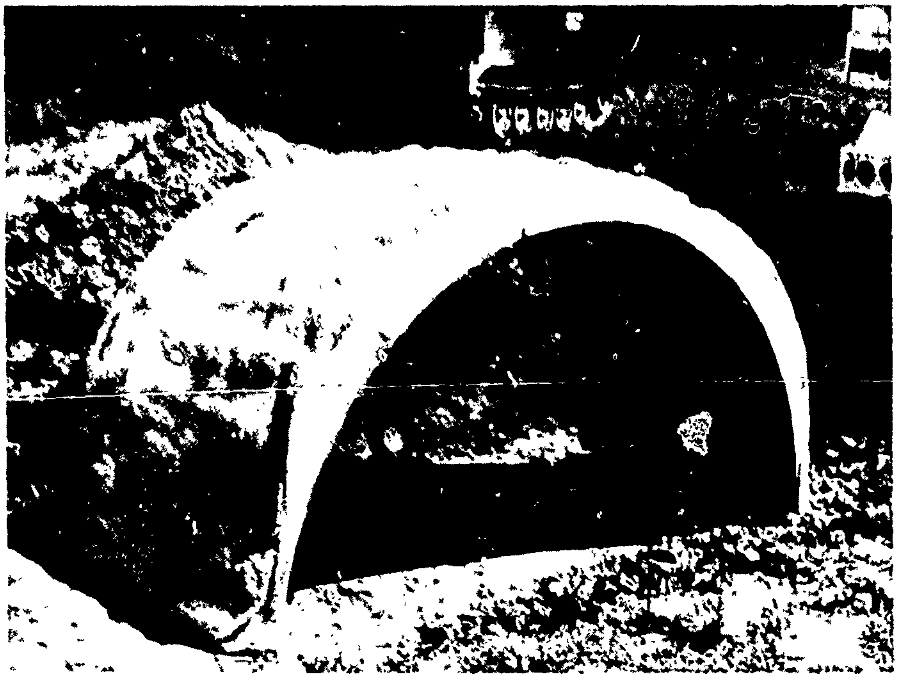


Figure 3. Arch test structure.

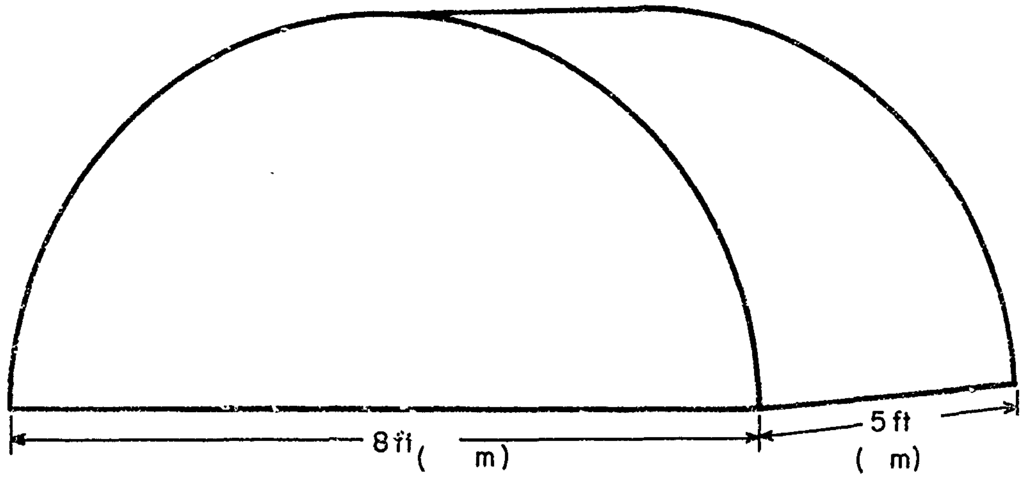


Figure 4. Dimensions of selected arch.

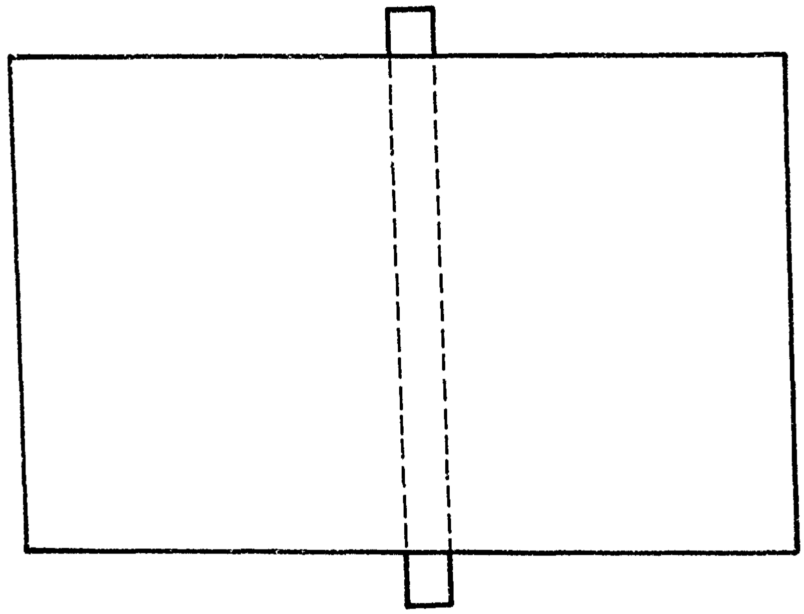


Figure 5. Projection of front and rear of TOW from cover (plan view).

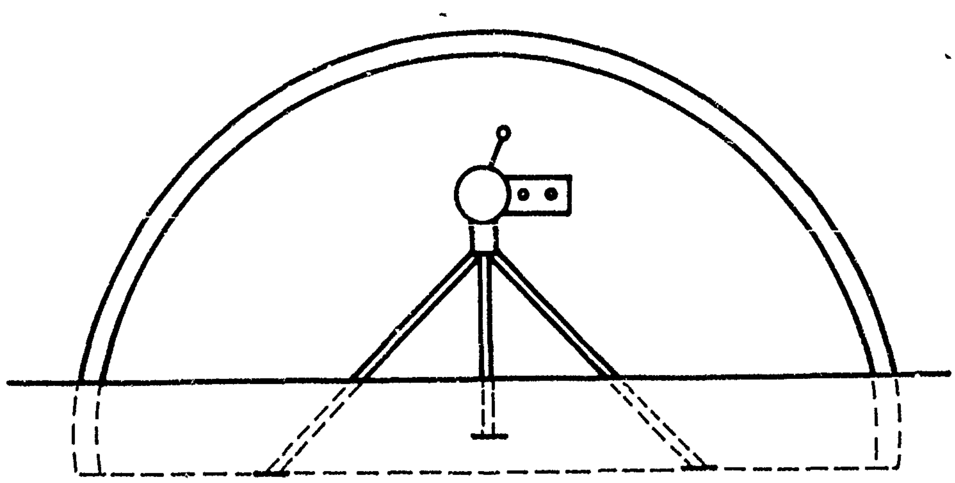


Figure 6. Front view of TOW in cover showing operating handle in closed position.

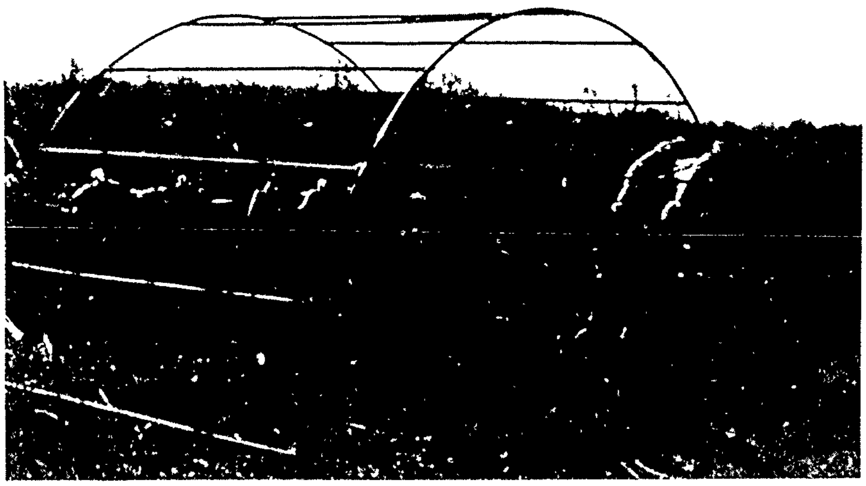


Figure 7. Lightweight tubular frame.

Figure 8. Folded tubular frame.

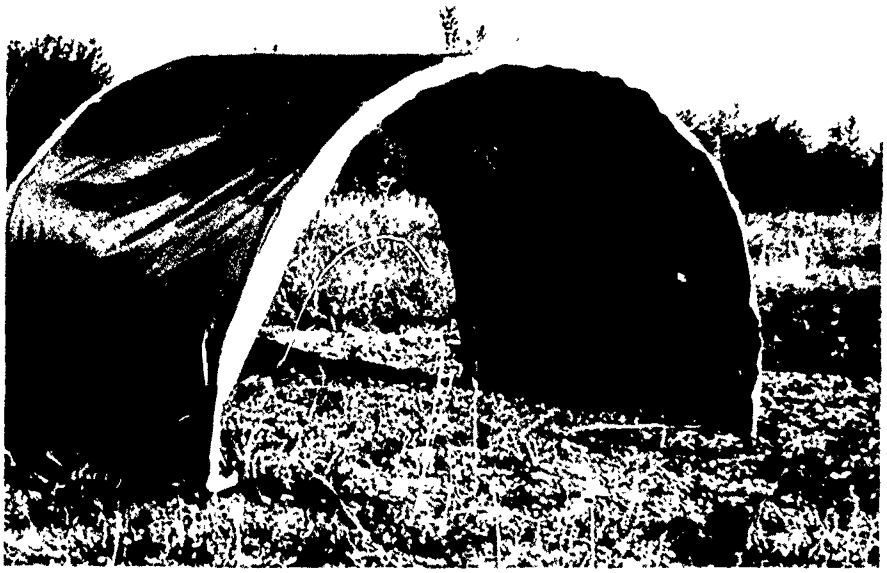


Figure 9. Tube frame with fabric in place.

Figure 10. Opening at midwidth of foam/fabric bag.

Figure 11. Introduction of foam at midlength of foam/fabric bag.

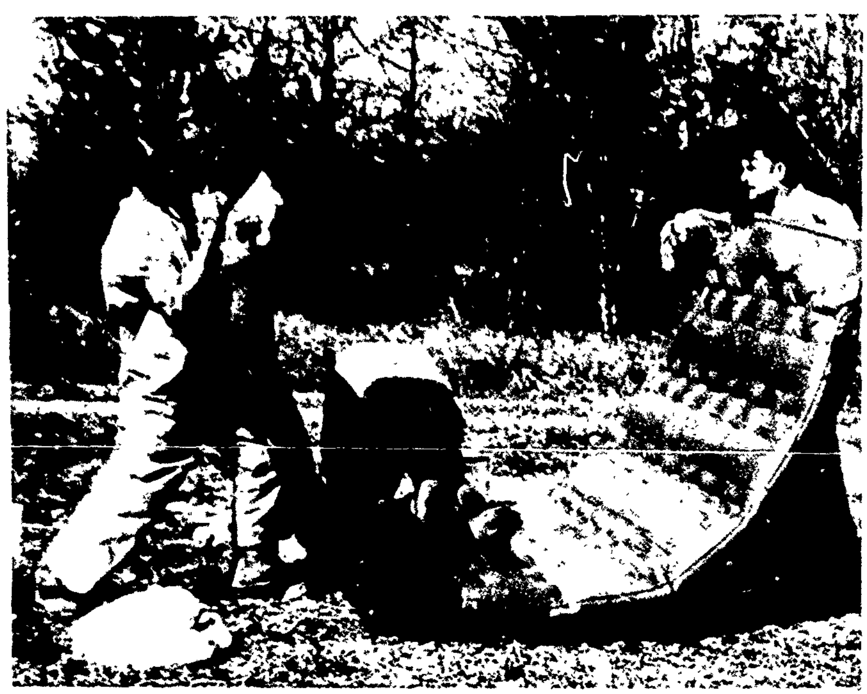


Figure 12. Forming arch by lifting foam/fabric bag.

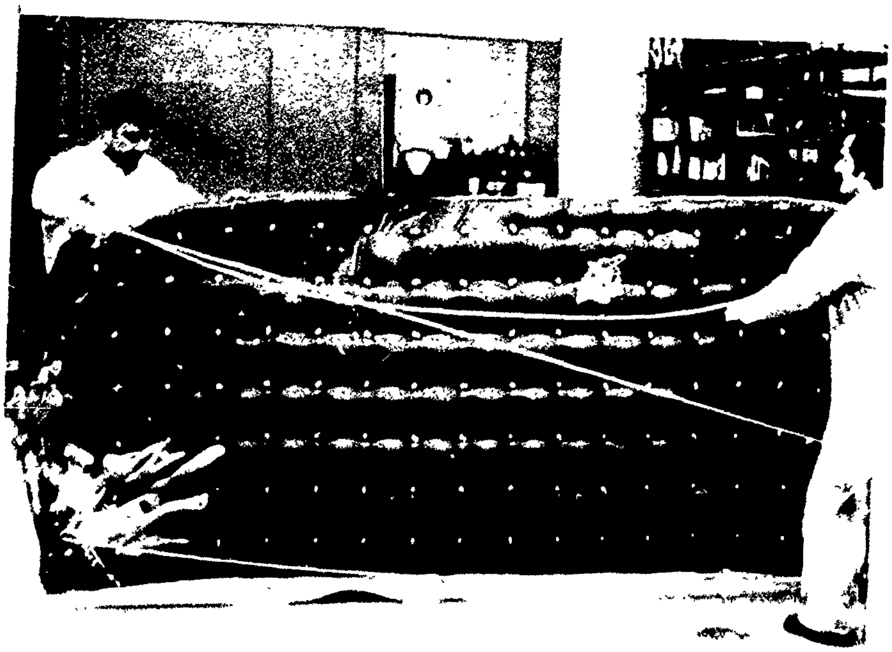
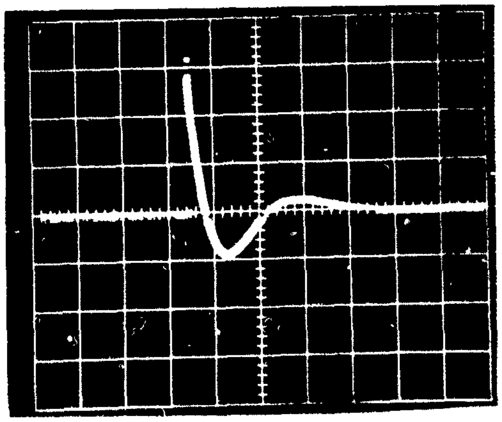


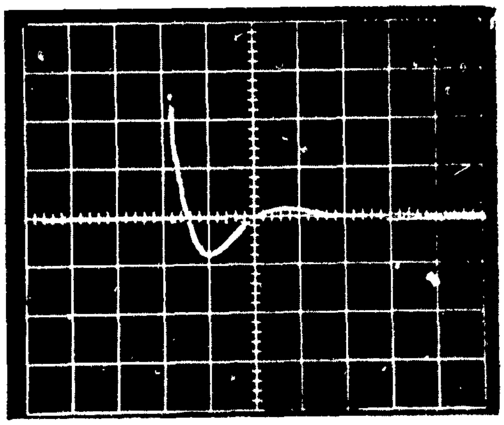
Figure 13. Forming arch by standing foam/fabric bag on end.

Figure 14. Forming arch by placing foam/fabric bag over tubular frame.

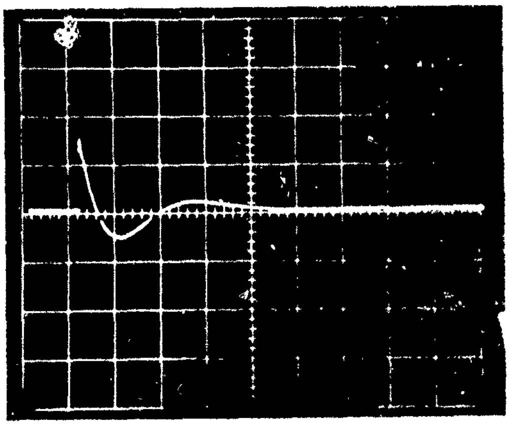
Figure 15. Nonuniform arch—failure.



Shot No. 1: 16 at 10 ft (3 m)
Vertical: 1 psi (6.9 kPa)/div
Horizontal: 0.1 second/div



Shot No. 2: 16 at 3.4 ft (1.1 m)
Vertical: 2 psi (13.8 kPa)
Horizontal: 0.1 second/div



Shot No. 3: 2 at 1.5 ft (.45 m) top of arch
Vertical: 4 psi (27.6 kPa)/div
Horizontal: 0.1 second/div

Figure 16. Typical acceleration curves for tests listed in Table 10.

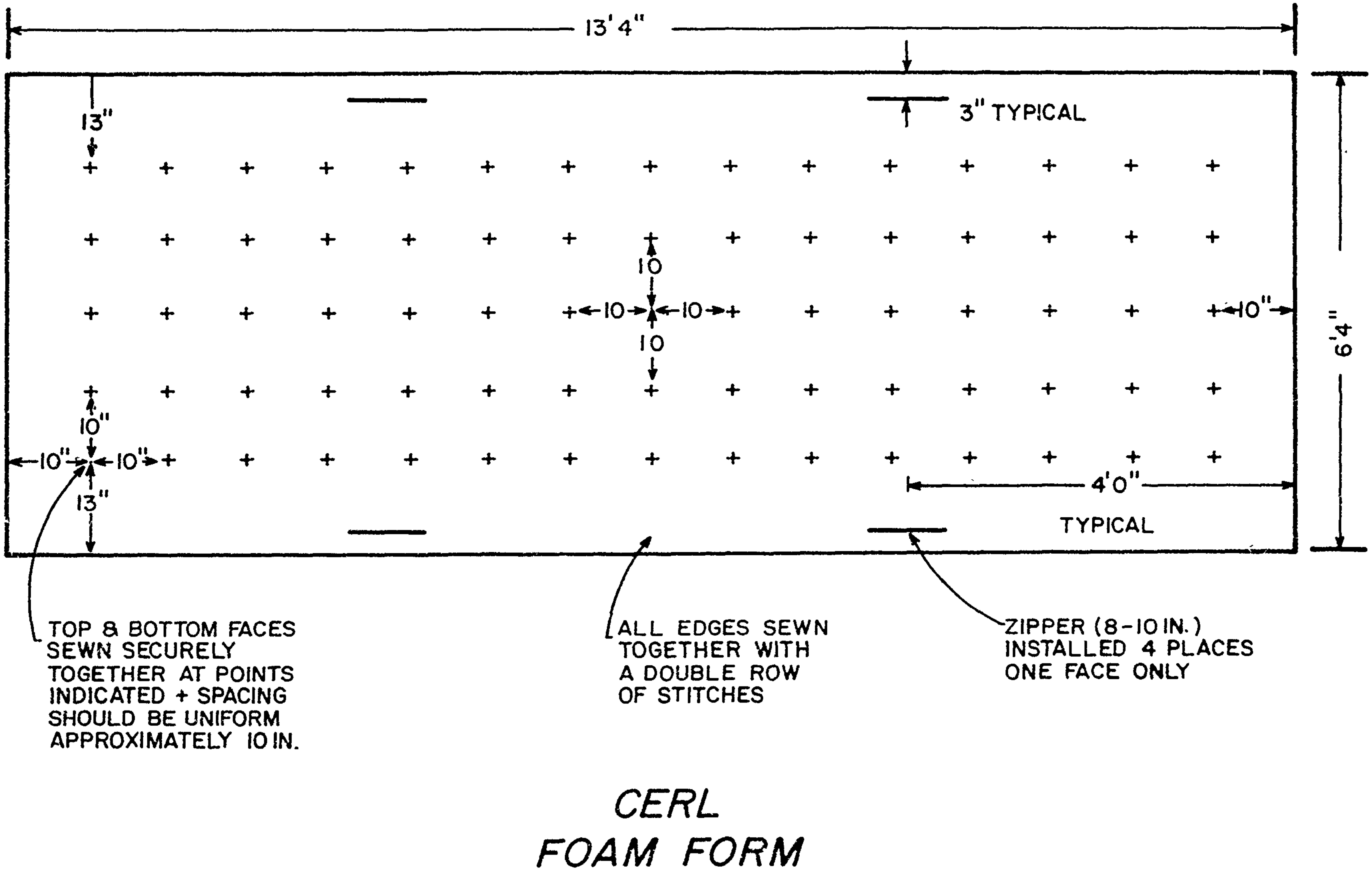


Figure 17. Sketch of fabric bag, including notes on fabrication methods and dimensions.

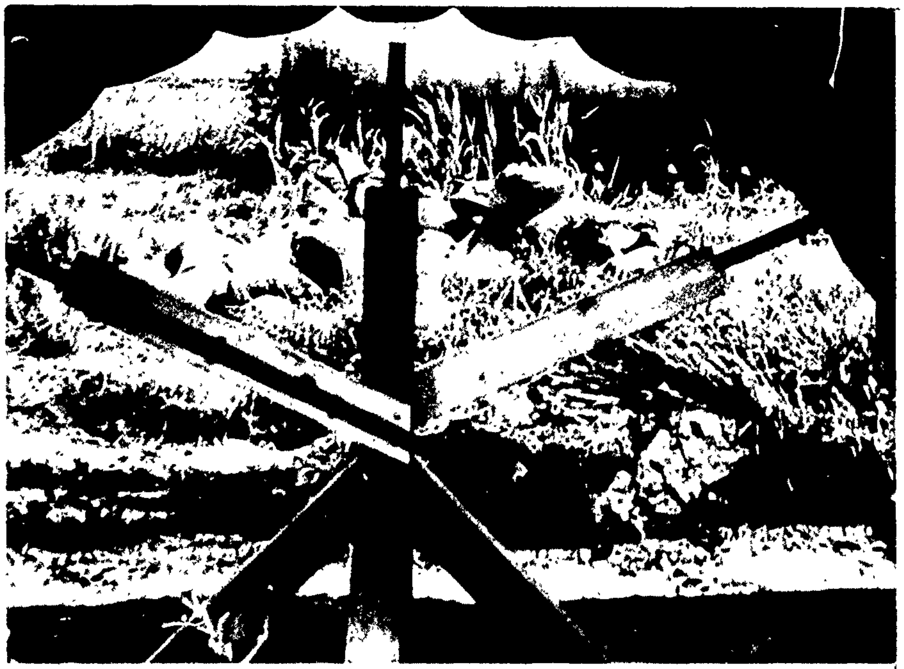


Figure 18. Device used to measure centerline and midheight deflections during arch loading.

Figure 19. Sandbags placed on top of soil against arch's ends and across the top of the arch.

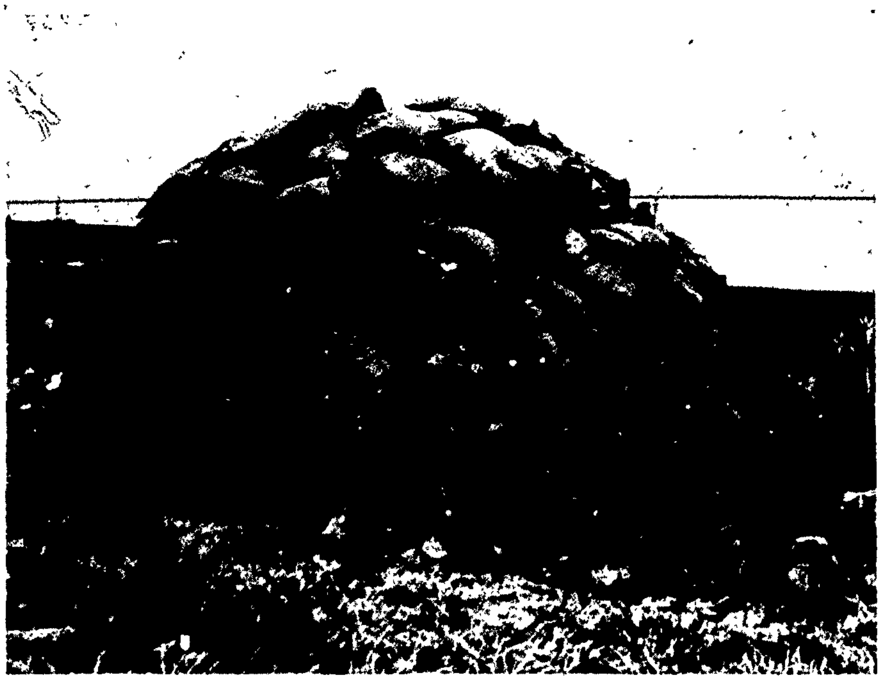


Figure 20. Fully loaded arch.

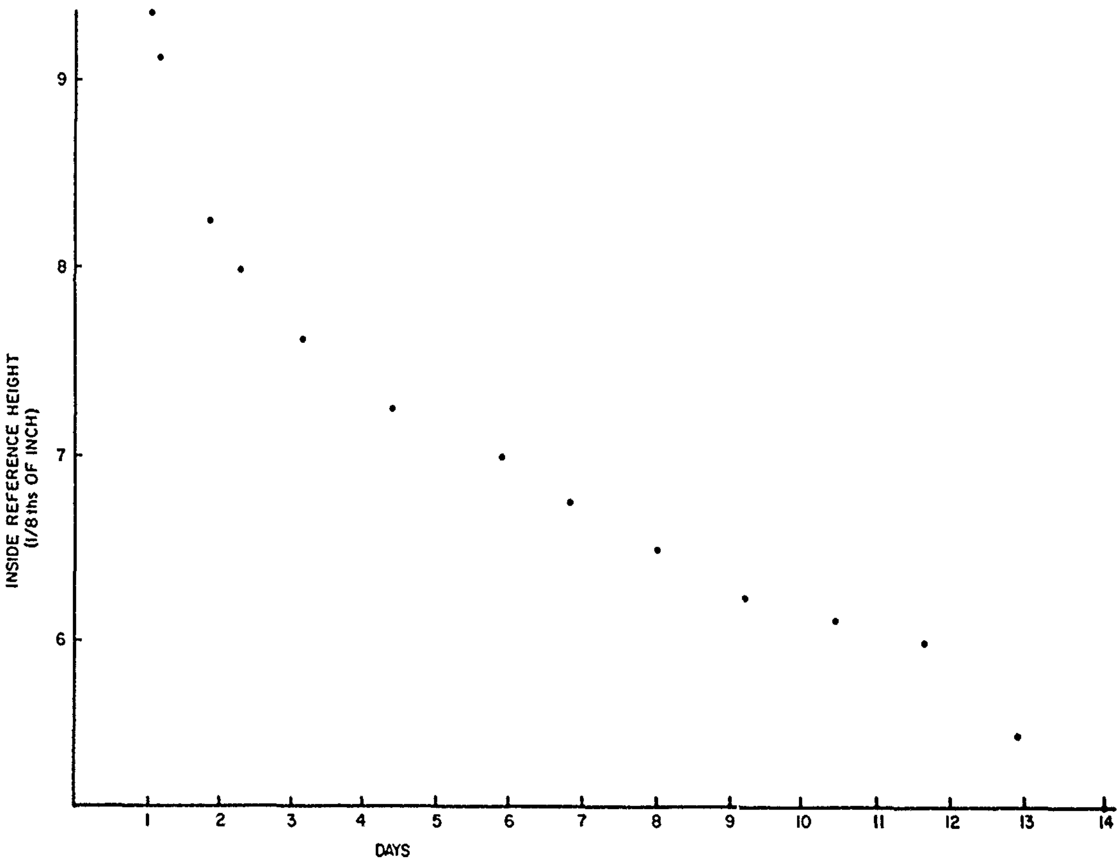


Figure 21. Deformation of arch over 2-week period.

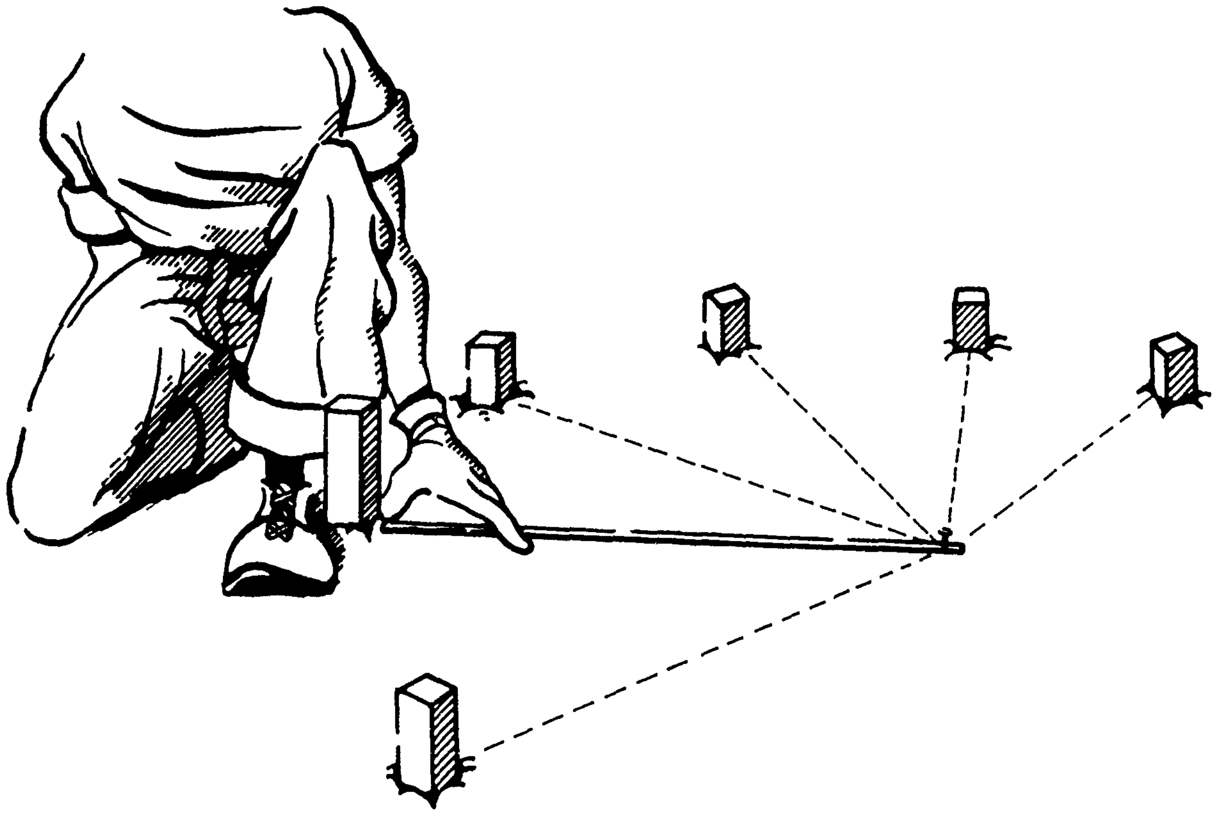


Figure 22. Using premeasured cord to set stakes in semicircle.

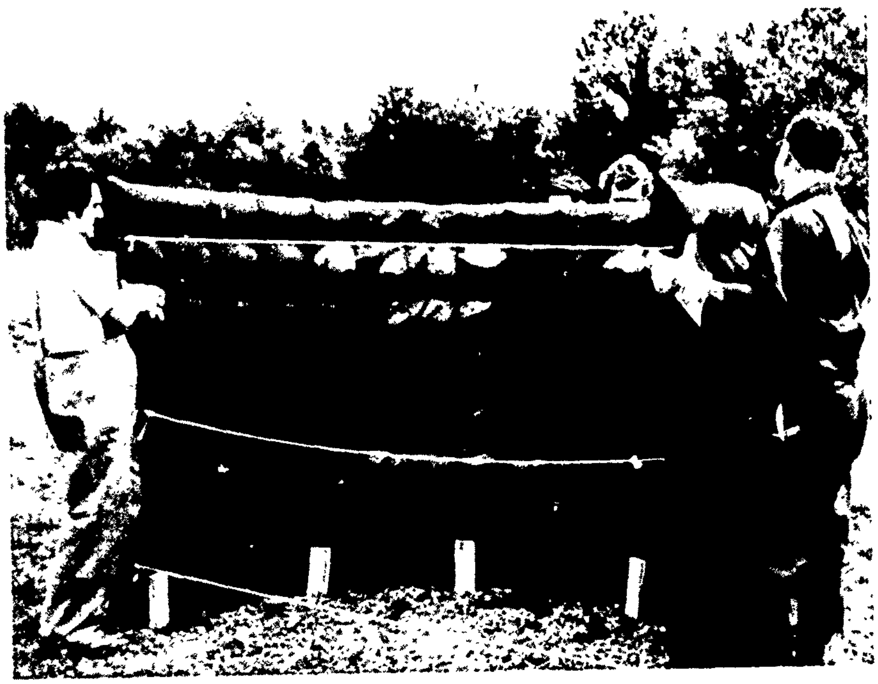


Figure 23. Forming foam-filled bag around stake semicircle.

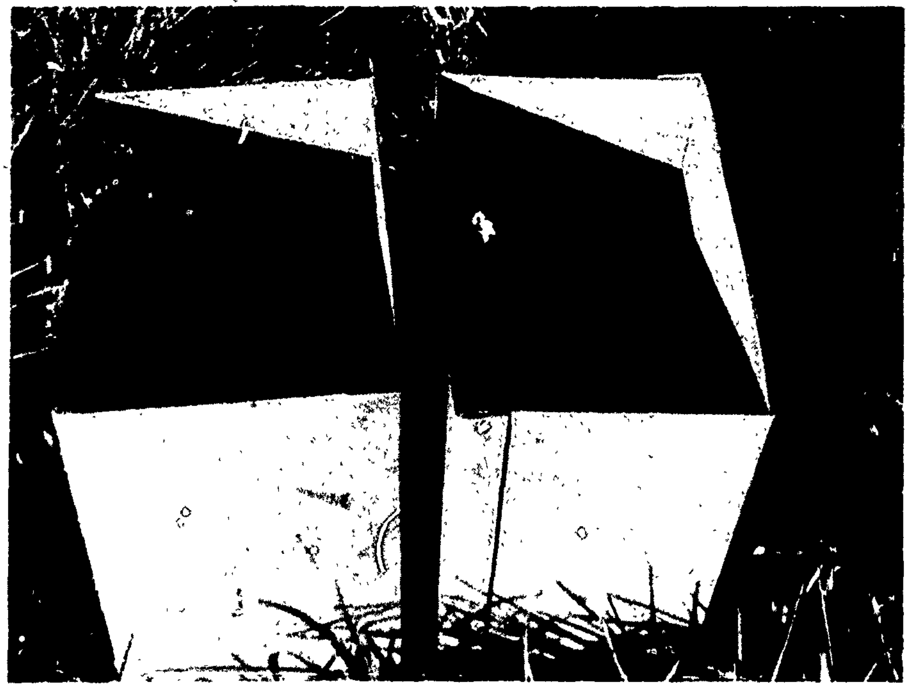


Figure 24. FOCOS kit container.

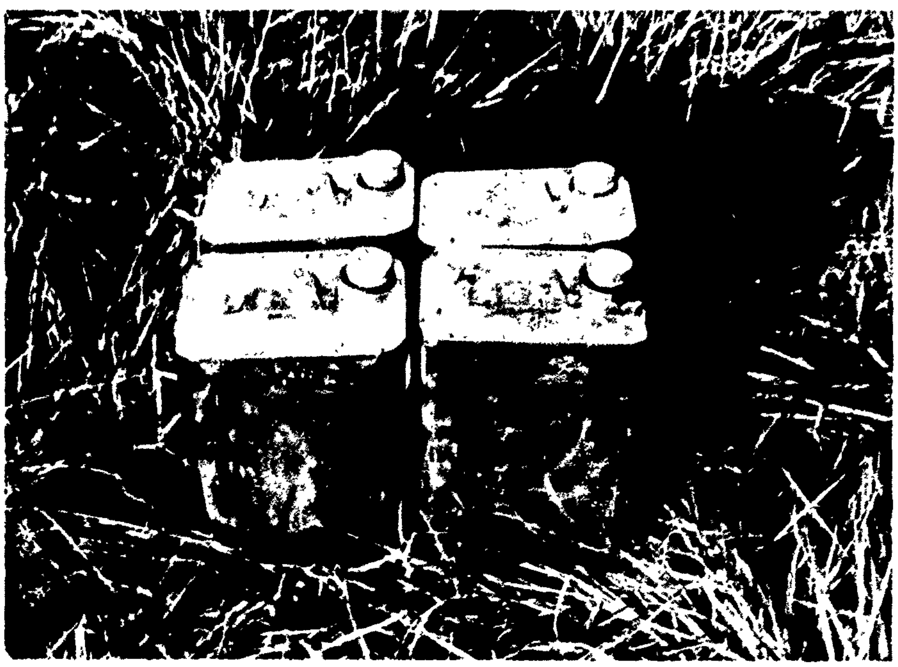


Figure 25. FOCOS kit foam-component containers.

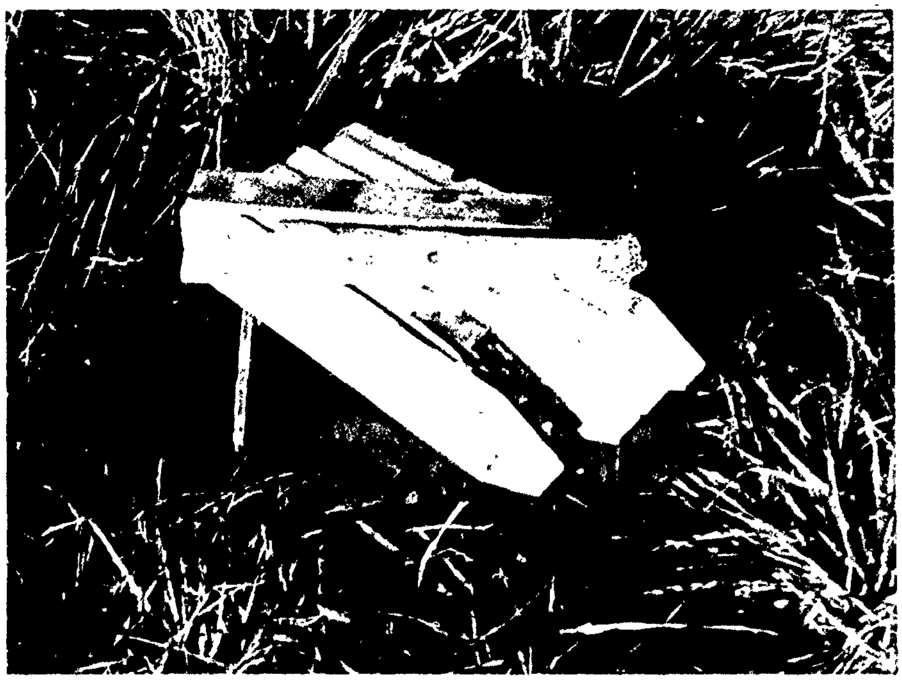


Figure 26. FOCOS kit fabric bag—folded—plus radius cord, two mixing paddles, and stakes.

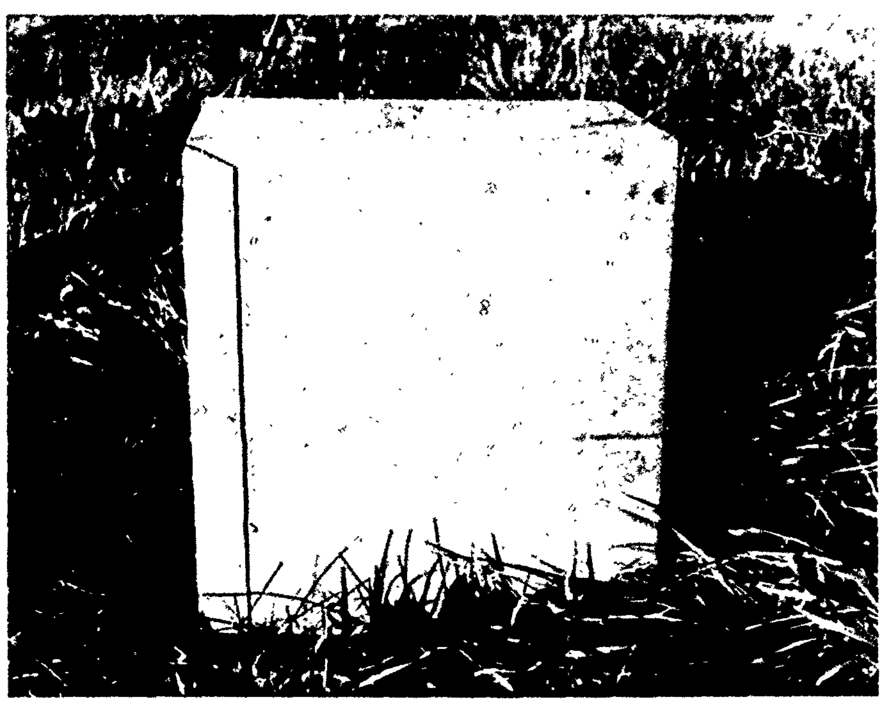


Figure 27. FOCOS kit—packed and closed.

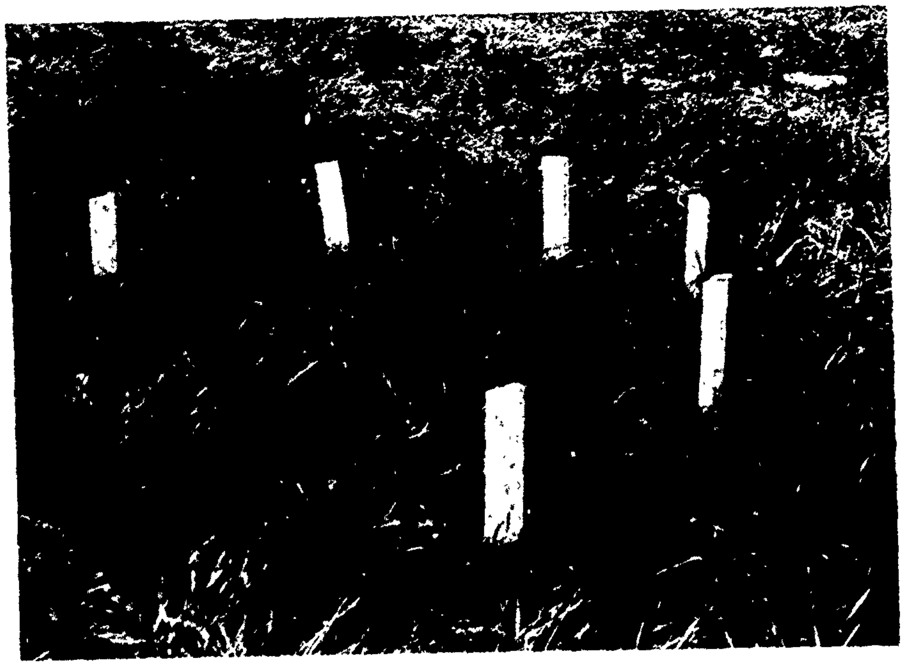


Figure 28. FOCOS kit stakes—in position.

Figure 29. Cardboard trough placed in FOCOS fabric bag zippered opening.

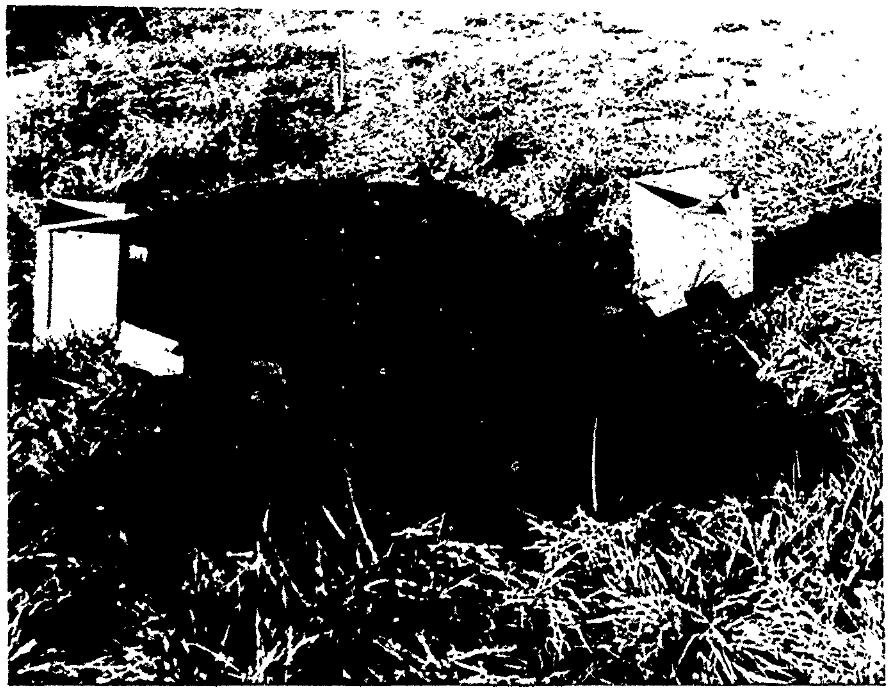


Figure 30. Placement of kit containers and mixing paddles.

Figure 31. Placement of foam-component containers.

Figure 32. Pouring foam components into container.

Figure 33. Mixing foam components.

Figure 34. Pouring foam mixture into FOCOS fabric bag.

Figure 35. Driving stakes against ends of arch.

Figure 36. Dirt piled 2½ ft (0.76 m) high on each end of arch.

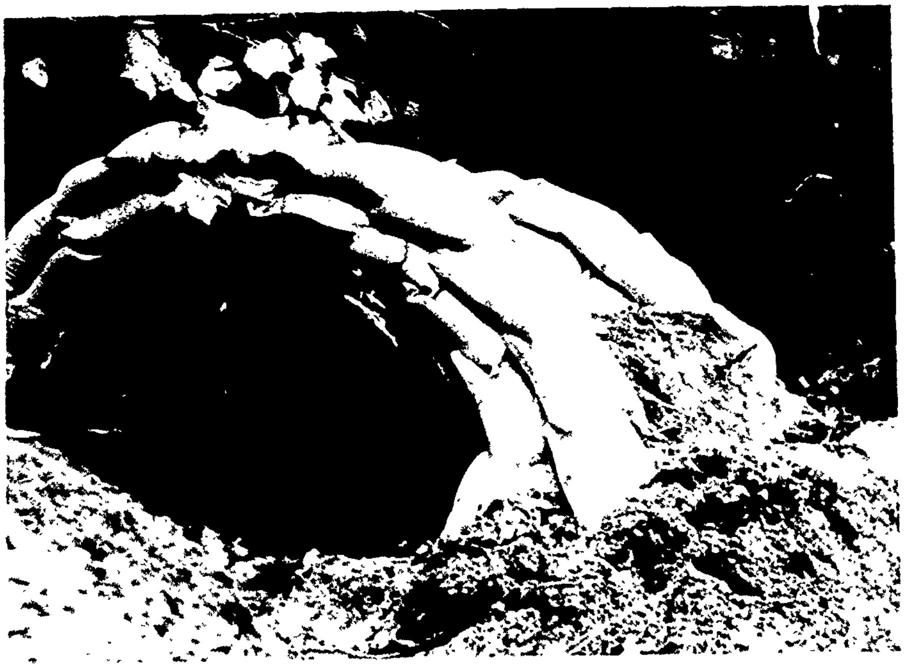


Figure 37. Sandbags loaded onto arch.

Figure 38. Adding soil cover to sandbag cover.

Figure 39. Arch failure—result of contact detonation.

Table 1

Reinforcing Materials

Material	Description
Insect screen	Aluminum woven mesh, 18 × 16 per inch (commonly used for window screening)
Nylon mesh	Woven ½ in. mesh nylon (commonly used for seine netting)
Welded mesh	2 × 4 in. welded 12 AWG wire mesh (commonly used as a fencing material)

Table 2

Foam Material Properties (Spray)

Density, lb/cu ft (kg/m^3)	2.0 (32)
Compressive strength, 10% strain, psi (kPa)	35 (241)
Compressive modulus, psi (kPa)	1000 (6895)
Tensile strength, psi (kPa)	38 (262)
Shear strength, psi (kPa)	25 (172)
Shear modulus, psi (kPa)	400 (2758)
Water absorption, lb/sq ft (kg/m^2)	0.033 (0.161)

Table 3

Preliminary Test Conditions and Results

Structure	Earth Cover in. (mm)	TNT Charge Weight lb (kg)	Charge Distance ft (m)	Calculated Pressure psi (kPa)	Results
Unreinforced dome	18 (.45)	16 (7.3)	10 (3) (side)	60 (414)	No effect
Unreinforced dome	18 (.45)	16 (7.3)	3.3 (1)	120 (827)	No effect
Unreinforced dome	18 (.45)	2 (.9)	1.5 (.45) (top)	800 (5515)	36 in. (.9 m) circular hole in top of dome
Nylon mesh reinforced dome	36 (.9)	2 (.9)	3.0 (.9)	120 (827)	No effect
Nylon mesh reinforced dome	30 (.76)	2 (.9)	2.5 (.76) (top)	300 (2068)	No effect; exposed top of dome
Nylon mesh reinforced dome	16-18 (.43-.45)	2 (.9)	1.5 (.45) (top)	800 (5515)	Broke dome in a circle about 36 in. (.9 m) across; foam remained attached by mesh
Aluminum mesh reinforced dome	30 (.76)	2 (.9)	2.5 (.76) (top)	300 (2068)	No effect; left about 1 in. (25 mm) of dirt on top of dome
Aluminum mesh reinforced dome	24 (.6)	2 (.9)	2.0 (.6) (top)	450 (3102)	No effect; foam exposed on top of dome
Aluminum mesh reinforced dome	18 (.45)	2 (.9)	1.5 (.45) (top)	800 (5515)	No effect; foam exposed on top of dome
Aluminum mesh reinforced dome	18 (.45)	81-mm M374 proj	1.5 (.45) (side)	800 (5515)	Buckled side of dome in about 4 in. (100 mm); no breach or fragment holes
Nylon mesh reinforced arch	18 (.45)	2 (.9)	1.5 (.45) (top)	800 (5515)	Arch broke center, and about halfway up each side, and collapsed
2 × 4 in. welded 12 gauge steel wire-reinforced arch	18 (.45)	16 (7.3)	10 (3) (side)	60 (414)	No effect
2 × 4 in. welded 12 gauge steel wire-reinforced arch	18 (.45)	16 (7.3)	3.3 (1) (side)	120 (827)	No effect
2 × 4 in. welded 12 gauge steel wire-reinforced arch	18 (.45)	81-mm M374 proj	1.5 (.45) (side, halfway up arch)		No effect
2 × 4 in. welded 12 gauge steel wire-reinforced dome	18 (.45)	81-mm M374 proj	15 (4.6) (side, from arch)		No fragment penetration
2 × 4 in. welded 12 gauge steel wire-reinforced dome	36 (.9)	16 (7.3)	3.0 (.9)	800 (5515)	5 ft (1.5 m) diameter circle broken through top of dome; pieces of foam are still attached to sides by reinforcing material

Table 4

Comparison of Foam Beams Reinforced With Various Materials

Specimen Identification	Reinforcing Material	Average Maximum Load, lb (kg)	Average Maximum Deflection, in. (mm)
PF	None—plain foam	400 (182)	0.6 (15)
NN	Nylon netting ½ in. mesh	408 (185)	0.7 (17.8)
PC	Parachute cloth 2 oz/yd nylon	725 (330)	2.13 (54)
GW	Grinding wheel glass mesh ¼ in.	1026 (466)	2.33 (59)*
GC	Glass cloth 7 oz Leno Weave	1000 (454)	2.33 (59)*
PE	Nicolon 66373 woven polyolefin filter cloth	895 (407)	2.33 (59)*
AS	Aluminum screen 18 × 16 per inch	805 (366)	1.55 (39.4)

NOTE: Specimens were 4 × 4 × 21 in. (101 × 101 × 533 mm), with the reinforcing material at the tensile face during test. Tests were conducted by the third point loading method.

*Did not break—deformed until specimen contacted loading machine bed.

Table 5

Reinforcement Selection Criteria

Criterion	Excellent	Good	Fair	Poor
Easily used in field environment	PC	AS, PE	NN	GC, GW
Weight	PC	AS, NN	GC, GW PE	
Bulk when folded	PC	AS	GC	NN, GW PE
Foam adhesion	PC, AS GW, GC, NN		PE	
Improvement in foam strength and/or stiffness	GW, GC PE, AS	PC		NN
Cost per unit area	PC, AS	NN	PE	GW, GC
Fabricability	PC	NN, PE	AS	GC, GW

Key
PC = Lightweight nylon parachute cloth
AS = Aluminum insect screen
PE = Woven polyethylene fabric
NN = Nylon netting
GC = Glass cloth
GW = Grinding wheel fabric (glass)

Table 6

Properties of the Handmixed Foam Used With the Foam-In-Bag Concept

Density, lb/cu ft (kg/m³); unrestrained	2.0 (32)
Compressive strength, 10% strain; psi (kPa)	36 (248)
Tensile strength, psi (kPa)	48 (331)
Shear strength, psi (kPa)	28 (193)
Mix time (hand stirring)	30 seconds*
**Cream time	40 seconds
Rise time	180 seconds
Gel time	130 seconds
Shelf life	More than 5 years in unopened containers

*All time values are for material at 70°F (21°C).

**Initiation of reaction indicated by change in appearance to a creamy color.

Table 7

Charge Distance/Overpressure Relationships in the Field Tests

Test*	Foam/Soil Interface Peak Pressure psi (kPa)	Positive Pressure Duration	Negative Pressure psi (kPa)	Negative Pressure Duration	BRL Pressure for Charge/ Distance Relationship psi (kPa)
1	3.1 (21.37)	<.01 sec	1 (6.89)	0.12 sec	60 (414)
2	5 (34.47)	<.01 sec	1.8 (12.41)	0.15 sec	120 (827)
3	7 (48.26)	<.01 sec	2 (13.79)	0.15 sec	approximately 800 (5515)

*Test numbers correspond to the tests described in Table 10.

Table 8

Conditions and Results of the Development Field Tests

Test Number	Structure	Earth Cover	Charge/ Projectile	Charge/Projectile Distance	Results
1	Sprayed in laboratory (2 × 4 in. No. 12 AWG reinforcement	18 in. (.46 m) sand	16 lb (7.3 kg) TNT	10 ft (3 m)	Collapsed arch*
2	Sprayed in field from prepressurized kit	18 in. (.46 m) sand/clay mixture	16 lb (7.3 kg) TNT	3.4 ft (.9 m)	Slight deformation
	Insect screen aid (2 oz nylon cloth)—reinforcement tube frame form				
3	Same as Test 2	18 in. (.46 m) sand/clay mixture	81-mm mortar round	Top of arch on top of fill	Collapsed arch
4	2 oz coated nylon foam/ fabric arch—nonuniform arch shape	18 in. (.46 m) sand/clay mixture	N/T	N/T	Collapsed under deadload prior to test
5	5 oz Neoprene coated nylon foam/fabric arch—slightly deformed shape	18 in. (.46 m) sand/clay mixture	155-mm	25 ft (7.6 m)	No effect
6	Same as Test 5	Same as Test 5	155-mm	10 ft (3 m) to side buried 3 ft (.9 m)	Deformed arch away from blast —slowly collapsed approximately 15 minutes later

*Collapsed partially because of deformation caused by nonuniform soil loading.

Table 9

Long-Term Load Test*

Day	Reference Point Movement (in.)			Daily Temperature		Remarks
	Left	Center	Right	°F high	°F low	
1	0	0	0	58	27	Start of test 20 Dec 78
2	0	−.63**	0	34	20	
3	0	−.75	0	41	28	
4	0	−.94	0	44	22	
5	0	−1.06	0	37	23	
6	0	−1.19	0	35	19	
7	0	−1.38	0	32	20	
8	0	−1.50	0	31	15	
9	0	−1.63	0	34	21	
10	0	−1.69	0	38	31	
11	0	−1.82	0	38	28	
12	—	—	—	32	25	No reading taken
13	0	−2.13	0	25	4	Significant rate change
14	0	−2.25	0	4	−8	2 Jan 79
15	0	−2.25	12	−4		
16	0	−2.25	0	10	3	
17	0	−2.25	0	11	−1	
18	0	−2.25	0	14	−3	
19	0	−2.25	0	16	2	
20	0	−2.25	0	2	−8	
21	0	−2.32	0	16	2	
22	0	−2.32	0	7	−2	
23	0	−2.32	0	11	−5	
14	0	−2.32	0	25	11	
25	0	−2.32	0	33	20	
26	—	—	—	20	−9	No reading taken
27	0	−2.32	0	12	−14	
28	0	−2.38	0	32	8	
29	0	−2.38	0	36	12	
30	0	−2.38	0	22	5	
	31	0	−2.38	0	34	Conclusion of 30-day test period
32	0	−2.38	0	34	29	
33	0	−2.38	0	29	18	
34	0	−2.38	0	27	15	
35	0	−2.38	0	34	22	
38	0	2.38	0	32	6	
49	0	−2.38	0	24	2	
60	0	−2.50	0	37	5	End of 60-day period

*Metric conversion factors: 1 in. = 25.4 mm; °F = 1.8 (°C) + 32

**A minus sign indicates a downward movement.

Table 10

Two-Week Load Test

Day	Reference Point Movement (in.)* Left	Center	Right	Remarks
1	0	0	0	Start of test Aug 78
2	0	− .50**	0	
3	0	−1.13	0	
4	0	−1.50	0	
5	0	−1.75	0	
6	0	−2.13	0	
7	0	−2.38	0	
8	0	−2.63	0	
9	0	−2.88	0	
10	0	−3.13	0	
11	0	−3.25	0	
12	0	−3.50	0	
13	0	−3.75	0	
14	0	−4.00	0	
15	—	−4.38	0	Conclusion of test Aug 78

*Metric conversion factor: 1 in. = 25.4 mm

**A minus sign indicates downward movement.

Table 11

FOCOS Kit

Component	Quantity	Weight	Approximate Cost
Box	1 each	3 lb (1.1 kg)	$ 4.00
Oblong cans			
2 gal (8 ℓ) capacity	4 each	4 lb (1.8 kg)	$ 8.00
Foam materials	8 gal	76 lb (34.5 kg)	$ 53.00
Fabric form			
(including material and fabric)	1 each	11 lb (5 kg)	$ 75.00**
Mixing paddles*			
½ in. plywood 2 × 12 in.	2 each	1 lb (.45 kg)	$ .50
Stakes			
1 × 2 × 12 in.	6 each	2 lb (.9 kg)	$ 2.50
Nylon cord	24 ft	—	$ 4.00
Radius cord	4 ft	—	
Total		97 lb (44 kg)	$147.00

*1 in. = 25.4 mm

**Probably lower in quantity procurement.

Table 12

Comparison of FOCOS and TOW-PRO Kits

Dismounted Position	FOCOS	TOW-PRO
Maximum dimension	1.5 ft (.45 m)	5.6 ft (1.7 m)
Volume	2.25 cu ft (.06 m³)	5.6 cu ft (.16 m³) (estimated)
Weight	97 lb (44 kg)	125 lb (57 kg) (estimated)
Cost	$147	$300
Jeep-mounted position		
Maximum dimension	2 ft (.6 m)	6 ft (1.83 m)
Volume*	4.5 cu ft (.12 m³)	26.6 cu ft (.75 m³)
Weight	194 lb (8P kg)	600 lb (272 kg)
Cost	$294	$1500

*Could be stowed in two locations as two halves (for convenience of loading).

Table 13

Conditions and Results of FOCOS Kit Tests

Test Number	Structure	Earth Cover	Charge/ Projectile	Charge/Projectile Distance	Results
1	10.5 oz coated canvas foam/fabric arch approximately 1 ft (.3 m) deep in trench	18 in. (.46 m) sand/clay	16 lb (7.3 kg) TNT	10 ft (3 m) surface	No effect
2	10.5 oz coated canvas foam/fabric arch approximately 1 ft (.3 m) deep in trench	18 in. (.46 m) sand/clay	16 lb (7.3 kg) TNT	3.3 ft (1 m) surface	No effect
3	10.5 oz coated canvas foam/fabric arch approximately 1 ft (.3 m) deep in trench	18 in. (.46 m) sand/clay	2 lb (.9 kg) TNT	Surface of fill halfway up shoulder of arch	Buckled arch in slightly; dispersed soil cover
4	12 oz canvas foam/ fabric arch approximately 1 ft (.3 m) deep in trench	18 in. (.46 m) sand/clay	155 mm	25 ft (7.6 m) surface	No effect*
5	Same as Test 4	18 in. (.46 m) sand/clay	155 mm	10 ft (3 m) buried 3 ft (.9 m)	No effect*
6	Same as Test 4	18 in. (.46 m) sand/clay	155 mm	3.4 ft (1 m) surface	Collapsed* half of arch
7	Same as Test 4	14 in. (.35 m) sand/clay	81 mm	Surface of fill half-way up shoulder of arch	Collapsed* half of arch
8	Same as Test 3	18 in. (.46 m) sand/clay	81 mm	Surface base of fill opposite side of 2 lb TNT test above (No. 3)	Slight* deformation

*No fragment entry into interior of structure.

Table 14

Foam Time/Density

Temperature, °F (°C)	Initiation	Rise (Time in Minutes)	Tack Free	Density lb/cu ft (gm/cm³)
Unmodified Foam				
70 (21)	1:30	6:23	8:30	1.76 (.028)
60 (16)	1:45	6:30	8:40	1.70 (.027)
50 (10)	2:00	6:42	8:50	1.68 (.027)
40 (4)	4:45	9:45	14:30	2.19 (.035)
30 (−1)	6:54	13:24	>15:00	2.61 (.042)
20 (−7)	10:54	19:00	>27:00	2.70 (.043)
10 (−12)	12:45	25:00	>30:00	3.45 (.055)
0 (−18)	>25:00	—	—	—
Modified Foam (as above + 3% catalyst)				
70 (21)	0:30	0:46	1:15	1.94 (.031)
60 (16)	0:30	1:00	1:30	2.00 (.032)
50 (10)	0:30	1:15	1:45	2.07 (.033)
50 (4)	1:08	2:10	2:45	2.19 (.035)
30 (−1)	1:30	3:00	4:05	2.71 (.043)
20 (−7)	2:25	5:30	7:00	2.94 (.047)
10 (−12)	3:05	6:13	7:00	3.42 (.055)
9 (−18)	5:00	9:06	>10:00	3.55 (.057)

Table 15

Performance of Foam at Low Temperatures

Temperature	Mixing Time	Foam Visible Expansion	Amount of Fill
32°F* (0°C)	45 seconds	4 minutes	90%
20°F*,** (−23°C)	60 seconds	6 minutes	75%
0°F*,**,† (−18°C)	120 seconds	—	—
Materials†† <60°F (15°C) Air—0°F (−18°C)	45 seconds	1½ minutes	100%

*The foam used was the "modified" version as shown in Table 14.

**The viscosity of the foam chemicals increases markedly at lower temperatures. This not only causes more difficulty in mixing but also causes less than ideal flow once inside the form.

†Air temperature was 0°F (−18°C); however, the wind chill factor was −20°F (−28°C). Wind chill factor is an adverse influence in exothermic processes such as foaming. The material also spreads out when poured into the fabric form, thus making heat loss more significant.

††The foam materials were maintained at 60°F (15°C) until about 10 minutes prior to mixing. Mixing, foaming, and forming the arch were conducted at 0°F (−18°C).

APPENDIX:

DEGREE OF PROTECTION STUDY

A probability study was performed to determine the degree of protection offered by the FOCOS system to the TOW weapon and crew as compared to a TOW position without cover.

Figure A1 illustrates the geometry of the problem addressed by the study. In addition, the following assumptions were made:

1. A shell within the lethal radius, R, can only do damage if:

   a. It explodes within r feet (complete destruction)

or

   b. It explodes so that there is a direct line of sight to the center of the ground under the shelter (the "vulnerable" space).

2. The rounds enter the space of the lethal radius in a random manner (not aimed at the TOW bunker).

3. The velocity and angle of descent of the round does not affect the probability (50 percent) of damaging the TOW or killing or injuring the TOW crew if the round explodes in the vulnerable space.

4. The probability of destruction within 10 ft (3 m) of the bunker is 1.00.

5. The volume occupied by the weapon and crew can be described as a point target with no significant effect on probability calculation.

The ratio of the vulnerable space to the total space (excluding the space within r feet) is only a function of the angle θ and equals:

$$\frac{\sec\theta - 1}{\sec\theta}$$

Thus the ratio is only a function of the width of the arch.

For an arch which is 8 ft (2.4 m) in diameter and 5 ft (1.5 m) wide:

$$\tan\theta = \frac{4\text{ ft}}{2.5\text{ ft}} = 1.6$$

Hence $\theta = 58°$ and the ratio = .47.

Thus, for any lethal radius, 47 percent of the space will be in the line of sight of the gunner and any rounds entering this space could kill or injure the

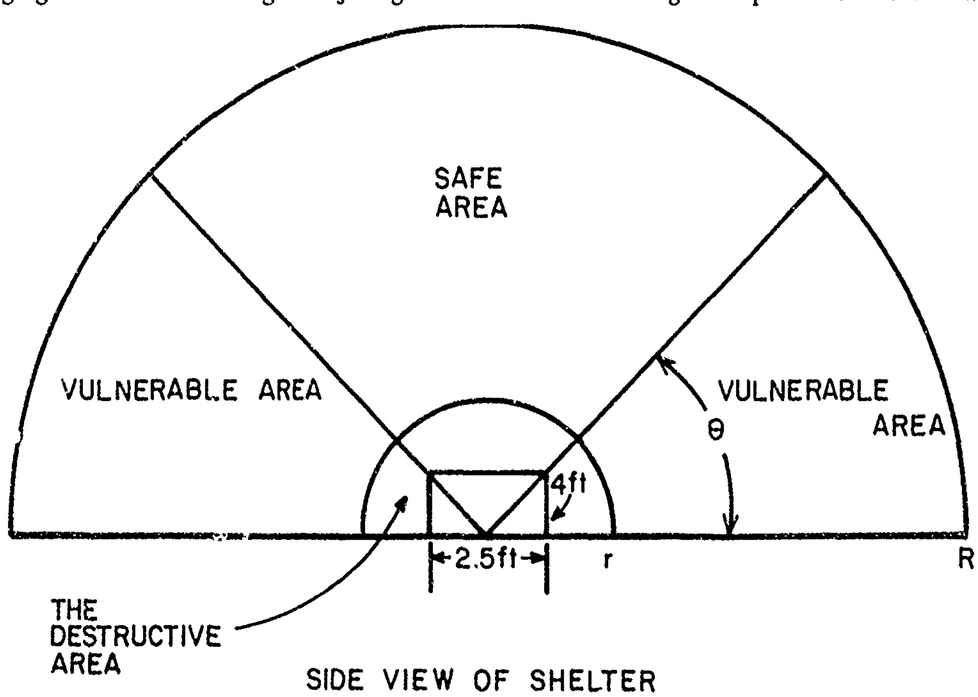


Figure A1. Geometry of problem.

weapon crew and destroy or damage the weapon. In other words, for a round randomly fired into the hemisphere of lethal radius, there is a probability of .47 that the round will be in the vulnerable space.

Probabilities

For the unprotected soldier, or for one within line of sight of an explosion in the vulnerable space, there is a .50 probability of death or injury or weapon damage occurring as a result of any given round.

No Protection

The .50 probability of an unprotected soldier surviving one round is a random variable following the binomial distribution. The probability of one or more damaging rounds in n rounds is:

$$\sum_{x=1}^{n} \binom{n}{x} p^x(1-p)^{n-x}$$

where p = probability of death or injury or weapon damage occurring as a result of a single round.

For example, the probability of one or more damaging rounds in three rounds is

$$\binom{3}{1}(.5)^1(.5)^2 + \binom{3}{2}(.5^2)(.5)^1 + \binom{3}{3}(.5)^3(.5)^0$$

$$= 3(.125) + 3(.125) + .125$$

$$= .875$$

Therefore, the probability of surviving three rounds = 1 − .875 = .125.

Protection: 5 ft (1.5 m) Width

For a soldier protected by a cover 5 ft (1.5 m) in width, θ is 58° and the ratio of vulnerable space to total space is .47. In this case, the probability of one or more damaging rounds out of n equals the probability of one or more rounds being in the vulnerable space times .50, where .50 is the probability of death or injury or weapon damage.

The probability of one or more of n rounds entering the vulnerable space is:

$$\sum_{x=1}^{n} \binom{n}{x}(.47)^x(.53)^{n-x}$$

For example, the probability of one or more of three rounds entering the vulnerable space is

$$\binom{3}{1}(.47)^1(.53)^2 + \binom{3}{2}(.47)^2(.53)^1\binom{3}{3}(.47)^3(.53)^0$$

$$= 3(.132023) + 3(.117077) + .103823$$

$$= 0.85112$$

Therefore,

probability(damage) = (.85112)(.50) = .42556.

The probability of surviving three rounds is:

probability(surviving three rounds) = 1 − probability(damage) = 1 − .42556 = .57444.

Protection: 8 ft (2.4 m) Width

For a soldier protected by a cover 8 ft (2.4 m) in width, θ = 45° and the ratio of vulnerable space to total space is .29. The probability of one or more rounds out of n rounds entering the vulnerable space is:

$$\sum_{x=1}^{n} \binom{n}{x}(.29)^x(.71)^{n-x}$$

For example, the probability of one or more rounds out of three entering the vulnerable space is:

$$\binom{3}{1}(.29)^1(.71)^2 + \binom{3}{2}(.29)^2(.71)^1 + \binom{3}{3}(.29^3)(.72)^0$$

$$= 3(.146189) + 3(.059711) + 024389$$

The probability(damage) = .64209(.5) = .32104; the probability(survival) = .67896.

Table A1 shows the probabilities for up to 10 rounds for the two widths.

Determination of Ratio

Three spaces—A, B, C—make up the vulnerable space:

R = lethal radius; r = destructive radius.

$$\tan\theta = \frac{\text{shelter height}}{\text{½ shelter width}}$$

Table A1

Calculations

5 ft (1.5 m) Width

$\theta = 58°$ Ratio = .47

n	Prob Being in Vul Space	Prob Damage × .50	n	Prob Being in Vul Space	Prob Damage × .50
1	.47	.235	6	.97784	.48892
2	.7191	.3596	7	.98825	.49412
3	.85112	.42556	8	.99377	.49688
4	.92110	.46055	9	.99670	.49835
5	.95818	.47909	10	.99825	.49912

8 ft (2.4 m) Width

$\theta = 45°$ Ratio = .29

n	Prob Being in Vul Space	Prob Damage × .50	n	Prob Being in Vul Space	Prob Damage × .50
1	.29	.145	6	.87190	.43595
2	.4959	.2474	7	.90905	.45452
3	.64209	.32104	8	.93542	.46771
4	.74588	.37294	9	.95415	.47708
5	.81958	.40979	10	.96745	.48372

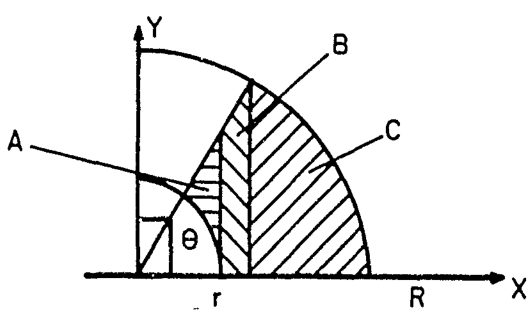


Figure A2. A, B, and C of vulnerable space.

1st intersection

$$x^2 + y^2 = r^2$$

$$y = x\tan\theta$$

$$x = r/\sec\theta$$

2nd intersection

$$x^2 + y^2 = R^2$$

$$y = x\tan\theta$$

$$x = R/\sec\theta$$

Space A

$$\pi\int_{r/\sec\theta}^{r} y_1^2dx - \pi\int_{r/\sec\theta}^{r} y_2^2dx = \pi\int_{r/\sec\theta}^{r} x^2\tan^2\theta\,dx - \pi\int_{r/\sec\theta}^{r}(r^2 - x^2)dx$$

(y_1 is the line $y_1 = x\tan\theta$;
y_2 is the circle $y_2 = r^2 - x^2$)

$$= \pi\left[\frac{x^3}{3}\tan^2\theta\right]_{r/\sec\theta}^{r} - \pi\left[x^2x - \frac{1}{3}x^3\right]_{r/\sec\theta}^{r}$$

$$= \frac{\pi r^3}{3}\left[\tan^2\theta + \frac{2}{\sec}\theta - 2\right]$$

Space B

$$\pi\int_{r}^{R/\sec\theta} x^2\tan^2\theta dx = \pi\left[\frac{x^3}{3}\tan^2\theta\right]_{r}^{R/\sec\theta}$$

$$= \pi\frac{R^3}{3}\frac{\tan^2\theta}{\sec^3\theta} - \frac{\pi r^3}{3}\tan^2\theta$$

Space C

$$\pi\int_{R/\sec\theta}^{R}(R^2 - x^2)dx = \pi\left[R^2x - \frac{1}{3}x^3\right]_{R/\sec\theta}^{R}$$

$$= \pi(R^3 - \frac{1}{3}R^3\frac{R^3}{\sec\theta} + \frac{1}{3}\frac{R^3}{\sec^2\theta})$$

Summing A, B, and C

$$\pi\left[\frac{2r^3}{3\sec\theta} - \frac{2r^3}{3} + \frac{R^3}{3}\frac{\tan^2\theta}{\sec^3\theta} + \frac{2}{3}R^3\right.$$

$$\left.-\frac{R^3}{\sec\theta} + \frac{R^3}{3\sec^3\theta}\right]$$

$$= \frac{2\pi r^3}{3}\left[\frac{1 - \sec\theta}{\sec\theta}\right] + \frac{\pi R^3}{3}\left[\frac{1}{\sec\theta} + 2 - \frac{3}{\sec\theta}\right]$$

$$= \frac{2\pi r^3}{3}\left[\frac{1-\sec\theta}{\sec\theta}\right] + \frac{2\pi}{3}R^3\left[\frac{\sec\theta-1}{\sec\theta}\right]$$

$$= \left[\frac{2}{3}R^3 - \frac{2}{3r^3}\right]\left[\frac{\sec\theta-1}{\sec\theta}\right] \times \pi$$

Total volume involved = $2/3\ \pi R^3 - 2/3\ \pi r^3$

$$\text{Ratio} = \frac{\left(\frac{\sec\theta-1}{\sec\theta}\right)\left(\frac{2}{3}R^3 - \frac{2}{3}r^3\right)\pi}{\left(\frac{2}{3}\ R^3 - \frac{2}{3}r^3\right)\pi} = \frac{\sec\theta - 1}{\sec\theta}$$

Note on the "Destructive Radius"

In all cases, 10 ft (3 m) was considered the destructive radius—if a round hit within 10 ft (3 m), the TOW is destroyed and the crew injured or killed. This space was subtracted out of all calculations for probabilities of survival.

The probability of a round entering the destructive space is:

$$\frac{2/3\pi(10^3)}{2/3\pi(R^3 - 10^3)} = \frac{1}{\frac{R^3}{10^3} - 1}$$

where R = lethal radius

For R = 50 ft (15.2 m) Probability(destruction) = .008

R = 100 ft (30.5 m) Probability (destruction) = .001

R = 150 ft (45.7 m) Probability(destruction) = .000296

Therefore, the probability (survival for n rounds) is:

$$1 - \sum_{x=1}^{n} \binom{n}{x} p^x(1-p)^{n-x}$$

$$= \binom{n}{0} p^0(1-p)^n$$

$$= (1-p)^n$$

Table A2 shows the probabilities for up to 10 rounds for the three lethal radius values.

The foam-earth arch increases the probability of weapon crew/weapon survival markedly over that expected at nonprotected positions. As more and more rounds are shot into the 50 percent lethal radius space, the probability of survival for unprotected crews/weapons reduces to 0.00, while that for protected crews/weapons reduces to .50.

Table A3 illustrates that, if the shell is within the 50 percent lethal radius, there is a probability of .50 of an unprotected soldier being killed or injured or of a soldier in the line of sight, i.e., in the center of the ground below the arch, being killed or injured. Table A3 assumes that the rounds are randomly fired into the lethal radius space, and thus the space may be broken into a "vulnerable" space (direct line of sight to the protected crew member) and a "safe" space (the shelter is between the explosion and the crew). For 100 rounds, the probability of survival with no shelter is .0000. The probability of survival with either 5 ft or 8 ft (1.5 or 2.4 m) shelter is .5000.

Note that the probability for surviving five rounds for an unprotected crew member is only .03, i.e., 3 percent. For a protected crew member, there is better than a 50 percent chance of surviving. Note also that increasing the length of the arch from 5 ft to 8 ft (1.5 to 2.4 m) makes less than .05 difference when seven or more rounds are fired.

Table A2

Probability of No Rounds Entering the Destructive Radius for Three Values of the Lethal Radius

	Number of Rounds									
	1	2	3	4	5	6	7	8	9	10
R = 50 ft (15.2 m)	.9920	.9841	.9762	.9684	.9606	.9529	.9453	.9378	.9303	.9228
R = 100 ft (30.5 m)	.9990	.9980	.9970	.9960	.9950	.9940	.9930	.9920	.9910	.9900
R = 150 ft (45.7 m)	.9997	.9994	.9991	.9988	.9985	.9982	.9979	.9976	.9973	.9970

Table A3

Probability of Survival (Number of Rounds)

Shelter	Number of Rounds									
	1	2	3	4	5	6	7	8	9	10
None	.5000	.2500	.1250	.0625	.0312	.0156	.0078	.0039	.0020	.0010
5 ft (4.5 m) Width	.7650	.6404	.5744	.5394	.5209	.5112	.5059	.5032	.5016	.5009
8 ft (2.4 m) Width	.8550	.7526	.6790	.6271	.5902	.5640	.5455	.5323	.5229	.5163

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Smith, Alvin
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